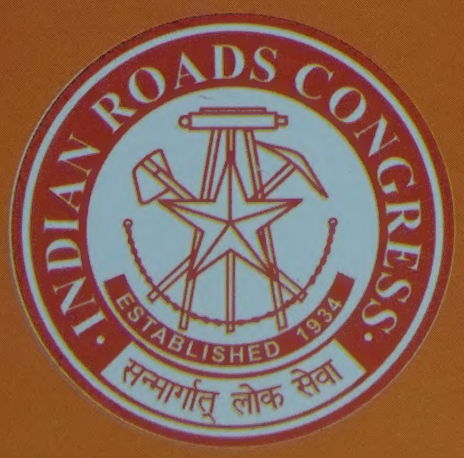
IRC:SP:35-2024

MANUAL FOR BRIDGE MANAGEMENT, INVENTORY, INSPECTION AND MAINTENANCE

(First Revision)



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Manual for Bridge Management, Inventory, Inspection and Maintenance *(First Revision)*

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BACKGROUND

With the growing number of bridges and structures on all categories of roads including National Highway, in particular, importance of Bridge Management has assumed far greater significance to ensure safety and serviceability of the structure throughout design life. Bridge Management involves multi-disciplinary knowledge, skill and expertise and require dedicated infrastructural arrangement to attain the intended objective.

Manual for Highway Bridge Maintenance Inspection, IRC:SP:18 was published in 1978. Guidelines for Inspection and Maintenance of Bridges, IRC:SP:35 was published in 1990 and thereafter Bridge Inspectors Reference Manual, IRC:SP:52 was published in 1999. Since then, there have been large scale and continuous development in materials as well as structural arrangements of bridges. The axle loads, vehicles concentration on bridges and structures have also diametrically increased. On the other hand, the practices of maintenance, repair, rehabilitation and strengthening of road bridges have remained too much wanting. As a result, either rehabilitation/retrofitting costs are exorbitantly increased or a lot of useful life of bridges and structures are wasted requiring reconstruction much before end of design life. Either case impacts economy and environment adversely. The documents, no doubt, need to be updated expeditiously so as to achieve correct and timely interventions.

The task of revision of IRC:SP:35 was assigned to Management, Maintenance and Rehabilitation Committee (B-8) during the tenure 2018-20. The draft was prepared by Dr. Sanjay Wakchaure. After re-constitution of B-8 Committee in 2021 the earlier subgroup was requested to carry out further work of revision. The document has been finalized by the sub-group of B-8 Committee comprising Dr. V.V.L. Kanta Rao, Dr. Sanjay Wakchaure, Prof. Rathish Kumar, Shri K.P. Prabhakaran and Shri P.Y. Manjure.

The document prepared by the sub-group was deliberated in number of meetings by B-8 Committee and finally approved in its meeting held on 17th February, 2023 as a substitution of the existing three Manuals/Guidelines and for placing before the Bridges Specifications and Standards Committee (BSS) Committee. The List of Personnel of B-8 Committee is as under:

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Tawade, D.O.	... Co-Convenor
Jaigopal, R.K.	... Member Secretary

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Indian Roads Congress

(Nirmal, S.K.)

The draft revision was considered by BSS committee in its meeting held on 28.06.2023 wherein it was desired that the draft be first reviewed by a standing committee before submitting to BSS committee. The Technical Standing Committee comprising of Shri R.K.Jaigopal, Shri D.O. Tawade & Shri D.K. Kanhere in its meeting held on 17.11.2023 recommended the draft revision for placing before BSS committee for its consideration. The BSS committee in its meeting held on 18.11.2023 after due deliberations approved the document for placing before the Executive Committee & IRC Council. The Executive Committee in its meeting held on 1st December, 2023 approved the same for placing before IRC Council. The IRC Council in its 226th meeting held on 02.12.2023 at Gandhinagar (Gujarat) approved the draft revision for printing. All the Members, Member Secretary, Co-Convenor and Convenor of the B-8 Committee deserve all the praise and recognition for their effort in bringing this very much needed revision of IRC:SP:35. The untiring work done by Dr Sanjay Wakchaure, Superintending Engineer, MoRTH who has contributed immensely in drafting the document is also appreciable.

While the structure of the document has been essentially retained, the contents have been thoroughly revised keeping in view international best practices, experience and knowledge gained over the period. The guidelines are to be looked upon as a document both as suggested "Good Practices" and "Mandatory Specifications".

The major changes effected to the previous documents are enumerated as below:

- The various aspects of Bridge Management including definition, objectives, activities and software framework have been introduced.
- As envisaged in IRC:SP:40-2019 the evaluation criteria for the various bridge elements have been made objective by prescribing the range of values for various distresses and photographs which will bring in the uniformity and transparency in condition valuation of bridges across the country.
- The Original Bridge report, Inspection Reports, Inventory and Inspection proformae have been revised.
- Number of photographs and description have been added for the various types of bridges & distress types. Bridge failure factors are also added.
- Mathematical model for the Bridge Health Index and Maintenance Priority Index have been introduced which will help in not only for assessment but for prioritization of bridges for their maintenance. Bridge Star Rating is also introduced.
- The qualification, experience and necessary training for the bridge inspectors is given in view of the changing working environment in the country.

It is hope that the provision of the manual shall go in a long way to change the improved quality of Bridge Management in the country.

CHAPTER 1
INTRODUCTION

1.1 Preamble

Bridges are lifelines of a Nation's road infrastructure and form the vital link of any road/highway network. Maintaining safety and serviceability of bridges during their life time deserves highest priority from socio-techno-economic considerations. During the last 50 years, a number of Reinforced Cement Concrete (RCC) and Pre-Stressed Concrete (PSC) bridges have been constructed on various roads all over the country. The number of bridges on highways are more than 1,50,000 and a total of about 10,00,000 bridges exist on Indian roads. The pace of construction of bridges has been particularly intensive in the last two-three decades. For a number of years, the bridge authorities had focused on planning and budgeting efforts and spent most of the allocated funds on new construction. Though, there are many bridges constructed in our country, the inventory database of the same is only skeletal with no important details.

Maintenance of bridges is equally important as that of construction and it is well understood that all civil engineering structures require regular maintenance and periodic repairs or replacement of some components during their service life. However, maintenance of bridges generally gets neglected because of the prevailing misconception that the bridges once constructed do not need any substantial maintenance particularly in the first couple of decades after construction. In the absence of proper database, regular inspection and systematic approach towards the bridge maintenance, presently, the maintenance of bridges is in a rudimentary state and often, ad-hoc decisions are taken regarding bridge maintenance and management as a sort of fire-fighting operations or crisis management, particularly so when funds are limited, without appreciating the magnitude of the overall problem or instant priorities at road network level or project level. Only a few important bridges are closely examined on case-to-case basis for rehabilitation works and, lack of proper regular maintenance has led to deterioration of some bridges rather early in their life and incidences of premature structural deterioration and collapse of bridges have been seen and or reported in the recent past. As a result of more and more cases of bridge deterioration coming to light coupled with increased use of the existing stock of bridges and in the absence of strong and systematic approach towards the bridge maintenance, there have been instances that bridges which are "not so old" also had to be posted for restricted loading due to lack of proper maintenance and reporting regime. A few bridges have had to be replaced much earlier than their designed life. Overall, it is estimated that about 25% of the bridge stock is in some form of distress.

Failure of regular inspection of bridges over the years has resulted in lack of prioritization and in turn it has not been possible to optimize the utilization of meager maintenance grants. In several cases, crisis management was the driving force behind initiating the maintenance and/or the rehabilitation actions. Also with more and more cases of bridge deterioration coming

to light, additional resources will have to be provided hereafter towards maintaining the existing bridges.

1.2 Manual on Bridge Management System (BMS)

Considering that the numbers of bridge assets are increasing rapidly in the country, there is a need to build a scientific and rational approach for timely monitoring, evaluation and prioritization of allocation of funds for maintenance of bridges based on principles of bridge management systems. The development of the bridge management system should be based on a comprehensive methodology taking into account the actual condition of different components of a bridge and possible cost-effective solutions for maintenance/ repairs/ rehabilitation/ strengthening for allocation of budget for the maintenance of the bridges on priority basis. Also, providing mobility and safety to the road users is of paramount importance. Attention in the next few decades should therefore be focused on the preservation and rational management of the large number of bridges built in the past. The aim shall be to maintain, repair, rehabilitate and strengthen the old bridges which have deteriorated due to inadequate maintenance and ageing. Additional resources will have to be provided hereafter towards maintaining the existing bridges and the same should be used in such a way that they yield the greatest possible benefit to society at the lowest possible cost as in several countries for prolonging the life of existing assets. This also emphasizes the need for optimal utilization of resources by carrying out technically correct remedial measures at the right time and on the right elements. In view of this, there has been a pressing demand by the user agencies like state PWD"s, NHAI and controlling agencies like MoRT&H to have a suitable system for prioritization of bridges for allocation of funds for maintenance, rehabilitation and strengthening.

The Indian Roads Congress (IRC), realizing the paramount need for maintaining these assets, had published IRC:SP:35-1990 "Guidelines for Inspection and Maintenance of Bridges" wherein various aspects of bridge inspection and maintenance were elucidated and strategies for implementation of these guidelines in a phased manner were dealt in detail as a part of Bridge Maintenance and Rehabilitation System thereby providing appropriate guidelines. Also, with an objective to provide uniformity in inspection of bridges in India, IRC had published IRC:SP-18-1978 "Manual for Highway Bridge Maintenance Inspection" in which all vital aspects like qualification and experience of inspection staff, periodicity of inspection, records to be maintained, complete list of items to be inspected, etc. were elaborated.

A detailed study of the above documents indicated that they essentially discussed different components of Bridge Management System (BMS). In a way, the IRC:SP:18 is like a sub-set of IRC:SP:35. It was decided by the previous IRC B-8 committee to merge IRC:SP:18 and IRC:SP:35 and prepare a manual on Bridge Management System essentially covering the inventory, inspection, maintenance and management of Highway Bridges, thus eliminating any overlapping between the above two documents. Bridge Inspector's Reference Manual (IRC:SP:52-1999) also covers Inspection form, Aspects related to bridge inspectors, List of equipment's, Inspectors report, Components of bridge types of bridges and distress types. Therefore, revised SP:35 shall be considered as a replacement of three documents that is

SP:18, SP:52 and SP:35. At present only a handful of States have compiled the data requirements of periodic inspection and maintenance of bridges. It is with the aim of providing uniformity throughout the country and to serve as guidelines to the bridge engineers that this Manual has been updated. Bridge management is not merely a routine but an art, wherein special techniques and exacting knowledge have to be applied to ascertain the physical condition of the structure and recommend suitable remedial measures for components affected.

It is envisaged that this manual would present a thoroughly revised and updated BMS by incorporating recent developments in approaches and techniques of BMS. Accordingly, this manual includes all vital aspects like status of inspecting staff, periodicity of inspection, records to be maintained, complete list of items to be inspected, criteria for evaluation and prioritization of either bridges or bridge components etc. Efforts have been taken to encompass various aspects of bridge management such that it not only supports & guides the bridge inspectors, but also the bridge engineers and administrators to evaluate, plan, execute and monitor the bridges in their jurisdiction. The manual shall essentially be useful to bridge inspectors, who are directly responsible for the management of bridges under their control, such that the resulting inspection reports would generate a general picture of the "Health-Status" of the concerned bridge with broad indicators towards distress-prone areas or already distressed components needing immediate attention. Thus, the proposed manual shall serve as a guideline for bridge inspectors and it provides information needed to be known by them for inspecting the bridges.

The BMS manual is expected to be looked upon not only as a guideline for good practices but also as minimal mandatory specifications for Bridge Management. It is hoped that the application of these guidelines will bring a paradigm shift in evaluation and managing bridges. Also, the manual will be instrumental in providing uniform guidelines across the country and pave the way for rational bridge management in India. The manual is expected to go a long way in not only maintaining old structures, by undertaking timely repairs/strengthening measures where necessary but also keeping a constant watch on our newly built bridges constructed with critical designs and optimum use of resources. In spite of the same, the need for a periodic review of the manual can hardly be over emphasized. Any suggestions on these guidelines for future revisions shall be appreciated.

It may be noted that the guidelines have been revised not only for normal types of bridges (which constitute the majority of existing bridges). Special type of bridges such as suspension bridges, extra dosed bridges and cable stayed bridges can also be managed on the basis of provisions in these guidelines although they are very few in numbers but their maintenance needs a more specialized approach especially for cables. While knowledge of bridge engineering is highly desired to appreciate the provisions of the guidelines, as far as possible, the technical contents and language have been simplified to make the Manual useful for the engineers of all levels. The State Governments are advised to translate this Manual into their respective local languages.

1.2.1 Need for Bridges Inspectors

Periodic and insightful inspection of highway bridges is an important essential input for any effective bridge management system for ensuring safe and uninterrupted flow of traffic on roads. Tremendous economic loss and the likely public criticism resulting from any disruption due to the failure of a bridge or its resulting "Highly Distressed" status requiring partial closure or load restrictions do not warrant any neglect or laxity in adequate maintenance and repairs of bridges. For that purpose, regular inspection through well qualified and adequately experienced bridge engineers is essential. Considering the increase in the number of bridges as a result of the rapid development of highways catering to the continuously increasing preference for road transport, the bridge engineer has now far more bridges to inspect and maintain than ever before. It has thus become necessary that the bridge inspecting engineer is assisted by a group of sufficiently qualified, properly trained and well experienced bridge inspectors to carry out more frequent inspection though preliminary yet comprehensive enough to include all listed components and sufficiently informative in respect of important details. Report from such reliable inspectors can go a long way in helping the bridge engineers to plan their priorities and correctly orient their inspections and the means of field inspections. Such purposefully directed timely inspection from the bridge inspecting engineers would ultimately expedite timely and effective removal of defects or rehabilitation measures which is the main aim of the inspection.

It is often found that the Bridge Inspectors are not fully qualified for the task. However, it is essential that they should be selected from the personnel who have certified engineering skills from an approved institution. The selection will depend on the consideration of the position of responsibility or familiarity with the bridges with experience of minimum of Five years in bridges. The proposed BMS Manual serves as a guideline for Bridge Inspectors and it provides information needed to be known by them in inspecting the bridges. Using this Manual such inspectors with experience should be able to carry out bridge inspection and management of the bridges.

1.2.2 Salient Features of BMS

The BMS involves several sub-systems such as identification, evaluation, planning and scheduled management of men, materials and equipment, reporting and performance evaluation. In the recent years, bridge inspection, evaluation and maintenance techniques and repair methods have been developed, modified or changed a lot.

The traffic loads, environmental conditions and seismic events exert undesirable stresses on the bridge structure. The sensors can be used in BMS to measure structural responses such as strains, deflections, temperature and humidity over time. Quantifying these elements and monitoring the bridge performance needs a distributed network that collects numerous data at each predefined time interval.

Techniques are available for performance monitoring and distress diagnostics of bridges which require a combination of visual inspection, non-destructive testing (NDT)/chemical analysis,

signature analysis and load testing, rating, etc. All the inputs from periodic visual inspection, NDT etc. lead to adoption of appropriate strengthening and rehabilitation measures.

The implementation of such advancements will help not only in maintaining existing structures but also keep a constant watch on our new sophisticated bridges constructed with critical designs and optimum use of materials. They will also help in better understanding about performance of bridges for future development of ways and means for bridge management.

Maintenance of the bridges involves a variety of operations from planning, programming and scheduling to actual implementation in the field and monitoring. It is essential that Cross-Drainage (CD) structures and appurtenances should be in good serviceable condition at all times and to extend the life of the road assets to the maximum extent possible. There are alternate options to be considered in evaluation and restoration of a damaged structure. Therefore, opinion of an expert bridge engineer in different related fields may be necessary to work out the appropriate management plan. The cycle of Maintenance, Repair & Rehabilitation includes: Inspection, Condition Assessment, Cost Estimation, Maintenance Planning, Preliminary Ranking, Project Level Ranking, Optimization, Tenders, Execution and Monitoring, as shown in **Fig. 1.1**.

Fig. 1.1 Cycle of Maintenance, Repairs & Rehabilitation

1.3 Scope

The Scope of the guidelines of the manual is as follows:

The manual covers the following elements of the bridge management system:

i) Inventory: The ways and means for inventory data collection system so that every bridge information collected is used for implementation of decisions made within Bridge Management System. Inventory of bridges through digital database by assigning unique identity number to the bridge to store information related to its inventory, inspection and maintenance procedures.

Modification of existing proformae to record various details of all components, original bridge features, results of inspection etc. It also includes requisite administrative information about the bridges such as name, location, administrative unit, type of road, construction data and technical details (foundation, substructure and superstructure), design loading classification, etc.

ii) Bridge Classification: It has been given on the basis of various factors so as to get acquainted the bridge professionals.

iii) Types of Inspection and Maintenance: These are the processes that are essentially needed to be carried out for the bridge. The manual presents revised guidelines for inspection of road bridges covering culverts, minor & major bridges as well as submersible bridges, grade separators including ROBs/RUBs. The types of inspections have been classified together with their respective periodicity and the level of engineering officers to inspect, depending on the type, importance and the environment in which the bridge is located. The guidelines also indicate various tools & equipment's necessary for inspection.

iv) Bridge Management: The guideline covers the following aspects of bridge management, but not limited to:

a) Defining the goals of bridge management and maintenance policy indicating the means to be employed and the strategies for implementation.
b) Digital database of inventory of bridges by assignment of unique identity number to store the information of the bridge related to its inventory, inspection and maintenance procedures.
c) Making a bridge inventory by the different methods and techniques of bridge maintenance.
d) The ways and means for inventory data collection system so that each bridge information collected is used for further implementation of decision making within BMS.
e) Evolving a methodology of utilization of data provided by bridge inspection.
f) Condition Assessment as regards to the bridge maintenance.
g) Causes of distress, their identification and a prognosis in the cause of deterioration in bridge.
h) Assessment of future requirements.
i) Prioritization of bridges for maintenance planning.
j) Decision making criteria and optimization of resources.
k) Risk Assessment.
l) Socio-economic and Environmental Assessment.
m) Bridge Management Framework.
n) Defining the research areas to improve the bridge maintenance techniques.

1.4 Applicability

This manual covers the general philosophy and Inventory, Inspection and Maintenance aspects of a Bridge Management System. IRC:SP:37-2010 " Guidelines for Evaluation of Load

Carrying Capacity of Bridges and "Guidelines for Methods and Techniques of Major Repairs, Rehabilitation and Strengthening of Bridges" have been issued as separate IRC documents / guidelines and the same may be referred to.

The guidelines are intended to serve as a document to be refereed to before making decisions related to bridge management. Recommendations included in the guidelines are of both the general and specific nature. However, guidelines do not exhaustively deal with specific technical issues. While these guidelines are complete and can be adopted as it is by the bridge owners, consultants, contractors, inspectors, engineers etc. the State or Authorities may adopt them to develop its / their own set of further detailed instructions, procedures and regulations in respect of its/their bridges. The guidelines are to be looked upon as a document both on suggested "Good Practices" and "Mandatory Specifications." As such this manual is to be used by all those who intend to implement Bridge Management System in a professional manner.

1.5 Definitions

In these guidelines, the definitions which have been mentioned in IRC:5 and IRC:SP:40 are to be followed.

CHAPTER 2
BRIDGE MANAGEMENT SYSTEM

2.1 Bridge Management Present Scenario

Bridge Management (BM) deals with activities related to bridges "from their inception until their reconstruction". The present BM practices in India vary from State to State. There is no unified database available with either the owners or implementing agencies. The available database is usually inadequate. Although inspection is a very important activity in BM the same is not carried out systematically and at regular intervals. Such inappropriate inspections at irregular intervals may not result in generation of meaningful records and timely decisions for repairs. While most of the authorities carry out inspections and maintenance of bridges through their own engineers, however, some authorities are not well equipped and get this done through contractors and consultants. This necessitates a need for trained bridge inspectors.

The maintenance activity is mainly governed by economic and traffic considerations. Presently the criterion used is not rational based on engineering principles and is normally the subjective assessment by an engineer with experience or training in maintenance and repair works mostly at the functional level. For improvement of complex structures the assessment is supplemented by advice from a specialist or the assessment is completely left to the specialist. At times, investigations or testing for detecting the deficiencies or the presence of deleterious materials is done. However, there does not appear to be a systematic assessment procedure and evaluation of the general assessment as well as effectiveness of maintenance or repairs.

The present maintenance policy follows the reactive approach and aims at merely ensuring that sufficient work is done each year to prevent accumulation of work which would impose a heavy burden on future budgets. However, the same requires to be changed from reactive to preventive/proactive approach. Sufficient data is not available to quantify the present and future needs both technically and financially for appropriate planning and execution of maintenance & repairs. It may only be possible to express qualitatively whether the allocation of funds is sufficient to prevent the progressive deterioration of the bridge by pursuing a policy of preventive maintenance and repairs. No formal studies are usually made and expenditure justified by the costs and benefits obtained. In general the level of expenditure on bridge maintenance is rather low and the exercise of comparing the cost of bridge maintenance or repairs or strengthening with the capital cost for reconstruction or replacement is rarely done.

Regular and systematic inspection and necessary maintenance of bridge is not mandatory till now. Therefore, a rational annual programme for maintenance is not drawn up on the basis of which funds could be either asked for or given. The provision of funds in the budget is often made for maintenance of roads and bridges together i.e., no separate budget provision exists for maintenance of bridges. The funds are generally asked for on the basis of some established financial norms, say, a certain amount per 'm' length of the bridge and this includes the cost of ordinary maintenance and that of unpredictable work that is needed from time to time. The cost

of inspection, maintenance, repairs, rehabilitation, strengthening, improvement, expenditure on testing, traffic warning signs and control, etc. are also included in the same. The funds allocated normally are far short of requirement and consequently the maintenance and other repairs suffer.

In most of the cases there is no exclusive organization for inspection and maintenance of bridges. The personnel in Public Works Departments or Highways Organizations look after the inspection and maintenance of bridges along with the highways and other construction works. The engineering personnel learn by experience, but no formal training in this discipline is given. Thus, there is a need for an effective bridge management system. Dedicated funds and personnel is the need of the hour and should be made available.

2.2 Stages in Life of Bridge

The various stages in the life of a bridge are: inception, feasibility, detailed engineering, construction, inspection, maintenance, repair and rehabilitation, improvement and replacement/reconstruction. This is shown schematically in **Fig. 2.1**. All the stages are important and to be given due weight for maximizing the benefits. Often, the life of a bridge is classified into two types, namely Design Life and Service Life.

Fig. 2.1 Stages in life of a Bridge

Design Life: It is the period for which the structure is designed to withstand the anticipated loads and environmental actions.

Service Life: It is the period which the bridge is able to perform the intended function with

requisite safety and serviceability.

2.3 Bridge Management System (BMS)

Bridge Management encompasses all the stages as mentioned in 2.2 above. The objective of BMS is to plan, design, construct and maintain the bridges so as to provide the users a convenient, safe and comfortable service. Broadly, the BMS may be defined as below:

"Bridge Management System comprises all activities in order to plan, construct and maintain bridges from their inception to reconstruction with the requisite safety and serviceability of both the bridges & users with due importance to environment in an economical/optimal manner with the latest materials and techniques to the maximum satisfaction"

The development of BMS largely depends on the requirement and working environment of an organization. If BMS is adopted from elsewhere, howsoever sophisticated it may be, it will not serve the intended purpose. It would be necessary to develop one's own model taking into consideration the prevailing scenario, of course learning lessons from the others. The lack of exposure and awareness is also one of the reasons for not having a scientific BMS in place in India. It should be noted that piece meal attempts would not stand the test of the time.

Success of any management system is dependent on two basic modules viz., inventory and deterioration models. Before development of deterioration models present condition data is to be collected over a period time. In order to collect the condition data one should start with the manual survey instead of any advanced method. This is a necessity because at present this is the only method everyone is familiar with. Before adopting the advanced methods, the personnel must be well acquainted with the condition states criteria prescribed in the guidelines and appropriate methodology is to be devised, along with inspection proformae, to ascertain as how the periodic condition data shall be used further. Unless it is done the development of a comprehensive BMS cannot be ensured.

Structural deterioration and functional obsolescence reduce service life of individual components as well as structure as a whole. The success of a BMS is dependent, to a large extent, on its ability to predict the future condition with a reasonable accuracy. The deterioration models form a link between the measure of condition states and the factors affecting the deterioration. In this regard, three different deterioration models namely, deterministic, stochastic and artificial intelligence models are in vogue.

In the deterministic model, relationship between the factors affecting the deterioration and the condition of bridges is described by a mathematical or statistical equation. The stochastic model treats the deterioration process as the result of one or more random variables. These models are easy to develop, use and update and effective for analysis of a large network. When applied to project-level analysis, they are subject to limitations, especially reliability and consistency of condition rating which are dependent on the subjective judgment of bridge

inspectors rather than on quantitative physical parameters, such as material properties, stress conditions, structural behaviour, failure mode etc. Deterioration is a stochastic process and hence probabilistic models must be used. The Artificial Intelligence (AI) models use computer-based techniques. They are knowledge- based and comprise Expert Systems (ES), Artificial Neural Networks (ANN), Case-Based Reasoning (CBR) and Genetic Algorithm (GA). Structural deterioration is complex and requires intuition, judgment and heuristic knowledge of experienced engineers. Knowledge-based systems are application oriented, easy to develop, flexible enough to adapt to any condition and user needs, application-oriented and utilize the existing expertise. The condition of an element/component for routine works is assessed based on visual inspection. However, often visual inspection may not reveal the hidden defects and the quality of inspection is highly dependent on training and experience of bridge inspectors, available equipment's and in-service environment. For detailed investigation, Non-Destructive Testing (NDT), Structural Health Monitoring (SHM) and Load Testing need to be carried out. NDT equipment's/systems available nowadays are smaller, more flexible and accurate, easy-to-use, less expensive and more reliable. The data acquired by using NDT can indicate the extent of damage, initiation of deterioration process and exposure of elements to type of adverse environments and help in developing appropriate deterioration models.

Till recently there were no systematic studies regarding failure of bridges in India and only in 2020, CSIR-CRRI had compiled instances of bridge failures in India occurred during 1997-2017. Using such data and information gathered from agencies such as MoRTH, NHAI, BRO and other implementing agencies like State PWDs (based on the projects sanctioned), empirical methods for deterioration models can be developed so that the life span of highway bridges can be known.

The condition data collected can be transformed to an index or indices taking into consideration the components, their relative weights and condition state of component itself. These indices may be health index and or reliability index. Indices are very easy to formulate and do not require elaborate strength data. Similarly, priority index may be formulated for a network. These indices may be used for preliminary ranking at project and network level respectively. Other possible methods for preliminary ranking could be Net Present Value (NPV), Cost-Benefit Ratio (CBR) and Internal Rate of Return (IRR) etc. for various alternatives of maintenance option. Once the preliminary ranking is done funds may be allocated by using predefined criteria for States/Divisions. After funds are earmarked project level or network level fund shall be optimized. There are many ways to do this. The one or more objectives can be decided to optimize according to a single objective or multiple objectives. The objectives may be Minimum cost, Maximum life, Maximum safety, Minimum risk etc. BMS should be able to weigh all these options and not difficult to achieve them. The programming of software can be made according to the requirements to fulfill the objectives.

Broad outline and specifics of a BMS are given where necessary in these guidelines and all the implementing agencies may strive to develop BMS on the basis of prevailing environment and topography of the area.

2.4 Objectives of BMS

The development of BMS depends on the work culture and a system of an organization. The system developed for one country may not be suitable for another country. Although it may require some time to develop a comprehensive bridge management system it is desired that in the beginning it shall accommodate the experience gained elsewhere.

The various objectives of BMS may be enumerated as below but not limited to:

- To ensure collection of objective information (inventory, inspection, maintenance and repairs) on all bridges.
- To develop a database for computationally intensive long-term monitoring.
- To provide quantitative and authentic data based on the real-time condition of bridges.
- To maintain a bridge or a network of bridges in a satisfactory condition.
- To ensure a targeted level of service.
- To guarantee the safety of the users with specified risk.
- To determine present needs for maintenance, rehabilitation and replacement of bridges.
- To predict future needs among the various alternatives.
- To prioritize bridges for maintenance, rehabilitation and replacement.
- To allocate and use limited resources in a judicious manner.
- To predict the remaining service life and minimize life cycle costs.
- To ensure techno-economical feedback.
- To provide information to the users.

2.5 Task/Activities of BMS

Activities associated with BMS in order to fulfill the objectives, but not limited to the following:

- Maintaining an appropriate database
- Inspecting Bridges
- Defining Bridge conditions
- Predicting Bridge maintenance requirement and future condition

- Prioritizing bridges for maintenance, repair, rehabilitation and replacement
- Allocation of funds
- Identifying bridges for posting (monitoring and load rating of bridges)
- Cost effective alternative for each bridge
- Scheduling maintenance
- Accounting for actual bridge expenditure
- Tracking minor maintenance activities

2.6 BMS Modules

The BMS enables the engineers and administrators at all levels to select optimum solutions to achieve the desired level of service within the funds allocated and to assess the future funding requirements.

It should form the basis of decision making by incorporating it in work environment. The success of BMS depends on how the data is being collected, used and maintained over the period of time. Without appropriate institutionalization for resources and manpower to maintain BMS it will rarely succeed to achieve the desired results and fulfill the expectations.

In order to achieve the desired objectives and perform the designated activities, various modules can be developed. In the advent of latest development on computer technologies and their availability it is possible to have a comprehensive IT tool or software for BMS. The principle underlying development of BMS software is that it should be user friendly and at the same time it shall serve the purpose for which it is intended.

On the basis of objectives and activities BMS software may consist of the following modules separately or in combination but not limited to:

i) Inventory

ii) Inspection and Reports (Historical Data Analysis Module / Prior Maintenance, Repair & Rehabilitation data module)

iii) Accident Data for Bridges

iv) Condition Rating and Deterioration Models

v) Estimation of Remaining Life

vi) Load Carrying Capacity Module

vii) Risk Assessment

viii) Present and Future Requirement for Development & Maintenance

ix) Cost Estimation

x) Prioritization/Advanced Decision Support System Module (Network/Project Level)

xi) Fund Allocation and Expenditure Monitoring/ Budgeting Module

xii) Optimum Utilization of Funds

xiii) Tracking Minor Maintenance

xiv) Socioeconomic Evaluation

xv) Environmental Impact Assessment

xvi) Techno Economical Feedback

xvii) Reports (Standard/User specific)

xviii) Development and Maintenance Plans

xix) New Technologies for Construction and Maintenance

xx) New Materials for Construction and Maintenance

xxi) Traffic & Road Safety (Operational Restriction Management)

xxii) Public Interface/Feedback (General/Technical)

A brief description of some modules is given below:

- **Bridge Inventory**: It contains all administrative and technical information pertaining to a bridge or a network of bridges e.g., location, type, age, etc.
- **Inspection and Reports**: Original Bridge Report, Collection and maintenance of reports of all inspections and maintenance work carried out since opening to traffic. Many of the BMS modules are developed by using this information.
- **Condition States/Rating**: Present physical state indicating soundness of a bridge determined on the basis of visual inspection and/or testing.
- **Deterioration Rate**: How the bridge has deteriorated since opening to traffic due to increasing age and erosive effect of traffic and environment?
- **Prediction of Life**: Minimum expected life after the repairs & rehabilitation/maximum period up to which bridge can be subjected to traffic flow to serve as intended function.
- **Requirement of Inspection, Maintenance, Repair, Rehabilitation and Replacement**: when, what and how much?
- **Cost Estimation:** of inspection, maintenance, repair, rehabilitation and replacement of a bridge or a network of bridges.
- **Estimation of Life Cycle Cost (LCC)**: of bridge/bridge stock considering both direct and indirect costs.

- **Serviceability Rating**: Method by which ability of a bridge to safely bear the present volume of traffic is ascertained.
- **Load Rating**: Method by which ability of a bridge to load carrying capacity is ascertained.
- **Prioritization**: of maintenance, repair, rehabilitation and replacement – By ranking of bridges based on Condition/Load/Serviceability rating and/or Life Cycle Cost (LCC).
- **Optimal Utilization of Funds:** Reprioritization depending on the availability of funds and methods for maintenance, repair, rehabilitation and replacement.
- **Public Interface**

The details of some of the modules are given below:

2.6.1 Data Base Module

A pre-requisite for attempting any scientific system of management of bridges is to have a proper data base module comprising bridge inventory, bridge inspection record and maintenance, repair and rehabilitation data. The data base is the core module of the system and the other modules and sub modules which operate on the data to perform the function of bridge management.

2.6.2 Inventory Module

This module is one of the prime modules of the BMS. This module provides all the necessary information available regarding bridges i.e. spatial details and attributes such as name, age, structure type, location, purpose, traffic volume, topographical information, hydraulic data, geo-technical data, geometrical data, structural design data, construction data, maintenance data, name of executing agencies and construction & maintenance contractor, etc.

To develop this module, the following methodology can be adopted:

i) Preparation of a base map of area using Survey of India toposheets and/or satellite data.

ii) Collection of bridge related data from various Government agencies, such as State PWDs, NHAI, NHIDCL and MoRT&H etc.

iii) Creation of Bridge inventory database through Consultants

This module provides an easy and logical access to the bridge information database. This module facilitates predefined output forms corresponding to the routine queries. Collection of available data for bridges comprises of general arrangement and detailed design drawings of substructure and superstructure etc. from the bridge authorities as well as field surveys. A graphical interface can be implemented in the system.

2.6.3 Inspection Module

Bridge inspection module consists of data gathered and recorded while checking the condition of various spans during successive inspections. It may also contain the feasibility/DPR including drawings etc. There are different types of inspection in practice such as routine inspection, detailed inspection and special inspection. The routine inspection may entail cleaning the structural members and repair minor damages at frequent intervals.

The detailed inspection is carried out for all components of bridges by in house well trained bridge inspectors/engineers or engaging consultants.

The special inspection is a detailed investigation of a bridge structure or parts of it, when the condition or load-carrying capacity is about to reach an unacceptable level or instances of emergent nature like cyclone, floods, earthquakes, passing of heavy loads etc. occur.

The details of various inspections are given in **Chapter-6**

This module stores all the data/reports collected during the various inspections and maintenance work taken up from inception, detailed investigations like non-destructive testing if any, load carrying capacity tests carried out by the bridge authorities etc.

2.6.4 Historical Data Analysis Module/Bridge Maintenance, Repair and Rehabilitation (MR&R) Module

In this module, all the data pertaining to the history since their inception and condition of the bridges are collected, in addition to the basic design data and construction data. It contains maintenance, repairs or improvement work data including the recording / drawing of major repairs, traffic data and reports of exceptional events such as earthquakes, information to make decisions on bridges strengthening or load limits.

2.6.5 Condition Rating Module

This module comprises of subjective and/or objective rating of the bridges based on the inventory and inspection data. Material deterioration, as reflected by the distresses, will often reduce the material strength and thereby lowering the condition states.

2.6.6 Load Rating Module

This module comprises of a load carrying capacity program for rating of the bridges based on the detailed inspection and load testing. The module includes the facility for computing the load carrying capacity in relation to the distress condition of the existing bridge.

2.6.7 Advanced Decision Support System Module

Main objective of this module is to establish and formulate the basis for evaluation and prioritization of bridges for maintenance planning:

It shall help in the following:

- To minimise the Life Cycle Cost
- To minimise the total risk for all bridges
- To minimise the maintenance cost
- To maximise the performance of a system of bridges
- To maximise the usage of allocated budgets
- To maximise the economic and social benefits from the maintenance

Prioritization of maintenance must be based on carefully selected criteria and trade-off among them. The most common policies which help in achieving the above objectives fall into three categories: strength/safety, cost and socio-economic benefits.

Generally, social benefits are difficult to measure and quantify. The importance of each element/component with respect to function and safety of the bridge and the importance of the route is to be included in the model that calculates the ranking points for the bridge. The rank of each bridge, thus, reflects:

- The current condition
- The actual load capacity in relation to the required capacity
- The importance of each element for the function of the bridge
- The importance of the route that passes over the bridge.

This module generates a customized query system for maintenance, rehabilitation and strengthening of bridges and also prepares a prioritization list on the basis of ranking of bridges and funds availability.

2.6.8. Rehabilitation and Strengthening Module

This module deals with various strengthening measures to be adopted for different components of the bridge, if the load carrying capacity of the bridge is lower than the desired/required level. The guidelines for rehabilitation and strengthening of existing bridges have been given in IRC SP:40. In addition respective codes /guidelines may be referred to for Steel, Cable Stayed, Extradosed Integral or Similar Bridges.

2.6.9 Budgeting Module

On the basis of the various possible alternative for repairs & rehabilitation measures for the different components of the bridge, a cost effective solution is to be selected on the basis of the availability of funds.

2.7 Framework for BMS

In order to develop software for the BMS following framework as shown in **Fig. 2.2** is suggested by incorporating the various modules prescribed earlier. These modules may be either combined or separated in order to accomplish a particular activity on the basis of the data availability and the requirement.

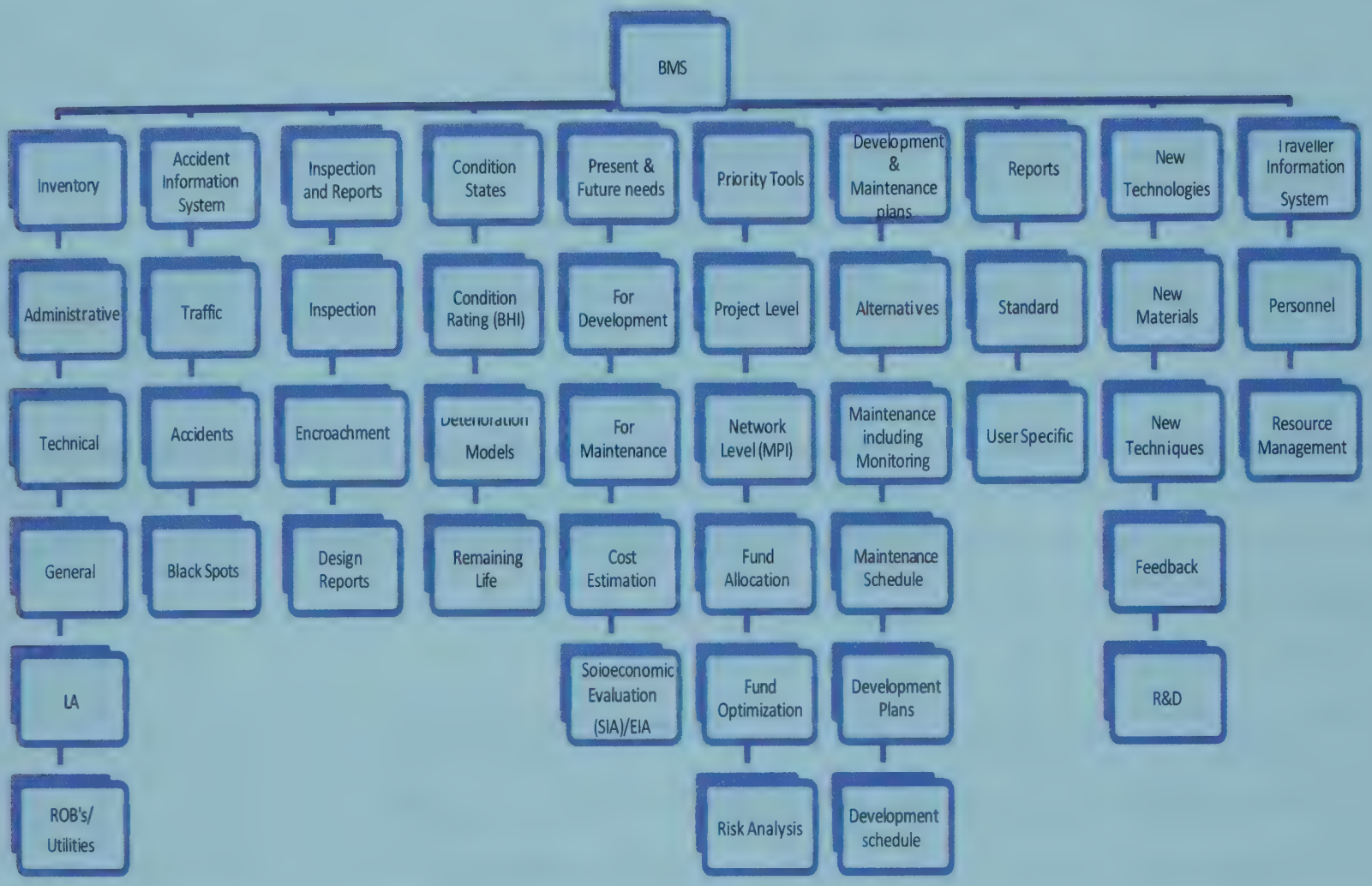


Fig. 2.2 BMS Architecture

2.7.1 Software Specifications

Hardware & software to be used for the development of BMS should be flexible enough for the up gradation at the same time it should not be dependent on any particular brand system for which every time fees are to be paid. Geographic Information System (GIS) layer shall not be Google based or such foreign based platform. It should be made as well as make in India. ISRO's BHUVAN and or GAGAN should be used.

2.7.2 Institutional Framework

An independent central unit must be developed to reap the fruits of scientific BMS. It may be supplemented by R&D activities and strengthened by Technical and IT experts in the fields. Either, 'National Centre' or 'Centre of Excellence' for development & management of BMS needs to be created. Initially it may be guided by the Departments officers for policy making and implementation but it should be independent of direct control of the State/UT. It may be supplemented by expert personnel through recruitment and/or by contract or consultants.

Dedicated fund shall be earmarked for operation and maintenance of this unit. This unit may also take over the research work of S&R Zones. Fund allocated and utilized must be on the basis of criteria prescribed in BMS. Separate and substantial funds shall be earmarked for maintenance of roads and bridges. Dedicated non lapsable fund may be created out of CRIF fund. State Governments shall be encouraged to develop their own RAMS/BMS as the geographical and environmental conditions and vary State to State. Ministry shall play a lead role in imparting funds and necessary direction in this regard. R&D activities may be carried out in house as well as Government & Private institutions. Government officers shall be given substantial incentives who are willing to contribute in R&D.

Ad hoc decisions at any level shall be avoided. BMS shall be the part and parcel of working right from the top to bottom. Unless there is a dependency on BMS it would not succeed. BMS should be developed in such a way that it not only contribute in decision making but also share the work load of maintaining data. It may also prove to be effective in promoting e-office culture. BMS may prove to be game changer and would ensure the quality of consultants being the only tool capable of doing work at a faster speed as well as with reliable quality.

2.8 Bridge Management Process

The phases of bridge management process are inspection, repairs for maintenance, evaluation of the bridge adequacy to fulfill the intended function, strengthening and rehabilitation and replacement or reconstruction.

In evaluation of load carrying capacity though safety consideration are of prime importance, considerations relating to flow and comfort of traffic, economic benefits/loss also should receive due weightage. Evaluation of bridges which appear to be in a critical condition should be carried out on emergency basis. The structural adequacy covers not only the load carrying capacity but also the overall hydraulic and structural soundness including aspects like scour, flood protection works, foundations, approaches, etc.

Rehabilitation or strengthening must be preceded by condition evaluation and proper assessment of repair needs. Some elements of the bridge structure such as expansion joints, bearings, waterproofing, parapets, railings, wearing courses, drainage spouts, etc. which account for nearly 15 to 20 per cent of the total cost of the bridge may not have the same life as that of the bridge and may require periodic repairs and replacement. It may also be economical to improve the maintenance techniques so as to limit the expenditure on major repairs or replacement. Improvements might be necessary on account of strengthening required to cater for increased loads or widening to cater for increased volume of traffic.

Replacement of a bridge becomes necessary only after the existing bridge has outlived its life or is considered not suitable for strengthening to cope with the increased demands or when the costs of strengthening and rehabilitation are too high compared to replacement costs considering the residual life of the existing structure. A factor in favor of replacement could be that traffic can continue to use the existing bridge while it may not always be possible to permit traffic on a bridge which is being strengthened or rehabilitated. On the other hand funds being limited, rehabilitation may allow more than one bridge to be brought back into service as against one replacement. Replacement should, therefore, be examined as an alternative solution to strengthening or rehabilitation.

2.8.1 Suggested Guidelines

Bridge management is a part of the general road management function as well as a part of the general bridge policy, the latter setting the standards from the first the design phase through construction and maintenance to the final replacement if need be. The concept of bridge management policy to be adopted should take into account availability of resources and forecast of the future needs. This would necessarily involve having a reliable data base of the existing stock of bridges, traffic loads, environmental and socio-economic constraints. The various options available deserve careful consideration. A proper rationale will have to be established for estimating the extent of priorities, ranking of overall bridge needs, including the existing stock.

Similarly, a judicious choice from the various options available for a given bridge like (i) doing nothing, (ii) regular maintenance, (iii) imposing load restrictions, (iv) keeping the bridge under extensive surveillance, (v) repairing, rehabilitation strengthening and (vi) replacement will have to be made and also prioritization will have to be done amongst the bridges at network level for various actions. So far as maintenance is concerned detailed policy proposals are given subsequently.

It is essential that before prioritization for repairs, inspections are carried out and evaluation of load carrying capacity is also done. The former, i.e., inspection, will decide the condition rating and the latter, i.e., evaluation of load capacity, will determine the load rating of each bridge. These will form the basis of ranking of bridges in need of repairs. The importance of each element in the functioning and safety of the bridge and also the importance of route are considered before a final ranking point is calculated for the bridge. The rank of each element will thus reflect:

i) The current condition

ii) The load carrying capacity in relation to the current traffic.

iii) The importance of the element for the functioning of the bridge.

iv) The importance of the route on which the bridge is located.

Alternative repair plans should be considered for the bridge in the top of the ranking list for which repair works can be carried out within available budgets. Selection among evaluated repair plans is normally based on the net present value of the repairs plan applying appropriate discount rate with possible consideration of traffic costs imposed on users by the work programme (detours etc.)

2.8.2 Organization and Personnel

Routine inspection and maintenance are best carried out by the departmental staff in charge of the concerned bridges. The principal and special inspections require special skills and experience and could be carried out by special departmental teams assisted by outside agencies as may be necessary. Likewise major repairs, rehabilitations and strengthening measures are specialized tasks requiring expert agencies for implementation. Depending on the work load in the organization it might be advantageous to operate departmentally and machinery procured for the purpose. These have to be supplemented by selected outside agencies to secure such special works according to specific needs. While sanctioning staff for such works it must be recognized that the norms of work load for them have to be more conservative than for routine construction and maintenance jobs.

CHAPTER 3

CLASSIFICATION OF ROAD BRIDGES

3.1 Bridge Attributes

Bridges are recognized or assessed based on their Strength, Stability, Safety, Serviceability, Durability, Functionality (structural/hydraulic/traffic), Aesthetic, Reliability, Social Importance and Economic Growth Potential etc.

Bridges can be classified into different types based on their various attributes. Some of the attributes are as below:

- **Function:** Road, Rail, Viaduct, Aqueduct, Rail-Road, Pipeline, Pedestrian etc.
- **Construction Material:**

  Masonry: Brick/stone/plain concrete blocks

  Reinforced Cement Concrete

  Pre-stressed Concrete Steel

  Timber bridges and

  Plastic, Fibre,

  Composite bridges
- **Inter-span Relations:** Simply Supported, Continuous, Cantilever etc.
- **Relative Level of High Flood Level:** Submersible, Non-submersible, Causeways
- **Span Length:** Culvert, Minor, Major, Long
- **Type of Superstructure:** Beam, Arch, Girder, Stiffened Girder, Truss bridges
- **Structural Form:** Arches, Simply supported spans, Continuous spans, Rigid frame type with decking integral with substructure, Cantilever or balanced cantilever, Suspension, Cable Stayed and Extra-dosed, I/T-beam, box girder, segmental etc.
- **Method of Connections:** Welded, Riveted, Rigid, Pin
- **Relative Position of Bridge Floor:** Through, Semi-Through, Deck
- **Clearance for Navigation:** Navigable/non-navigable, moveable, Bascule, Transporter, swing bridges etc.
- **Type of Loading:** 70R, 40R, Class AA, Class A & Class B
- **Life and Service:** Temporary, Permanent
- **Degree of Redundancy:** Determinate, Indeterminate

Bridge Materials

Many types of materials such as concrete, steel, wood, iron and stone have been in use to create modern bridges, while concrete and steel are the most commonly used materials in large modern bridges.

Advanced Materials

Some of the advanced materials that offer noticeable advantages over traditional construction materials are as below:

- Polymer Asphalt
- High Performance Concrete
- High Performance Steel
- Self-Consolidating Concrete
- High Strength Concrete
- Fibre Reinforced Concrete
- Fibre Reinforced Plastics

It is the type of material and environmental condition that demands the maintenance actions required over the period of time for the bridge besides its usage.

3.2 Bridge Components

For developing a methodology for inspection and systematic recording of observations, it is necessary to classify the bridge components in to distinct groups. Format for a bridge inspection report can be designed accordingly. They are also to be classified for determination of their relative importance and development of combined /overall condition of a bridge in the form of an index or otherwise. Accordingly, the bridge components are divided in to seven major components namely, Approaches, Substructure, Waterway/Channel, Foundations, Superstructure Appurtenances/Auxiliary works and Bearings. The corresponding sub-components of the major components as shown in **Fig. 3.1** are as follows:

i) **Approaches:** Alignment, Signage, Embankment /cutting, Railing/crash barriers /guard stones/rails, parapet etc., Approach slab, Approach joint, Side drains, Side Slope Protection

ii) **Substructures:** Abutment, Dirt wall, Weep holes, Wing walls, Abutment protection works, Pier/Pylon, Pier cap, Pier protection works,

iii) **Waterway/Channel:** River/channel bed, Guide bunds, Spurs, Retaining wall, Toe walls, Floor/channel protection, Apron, Curtain/cut off walls, Ground/rock anchors

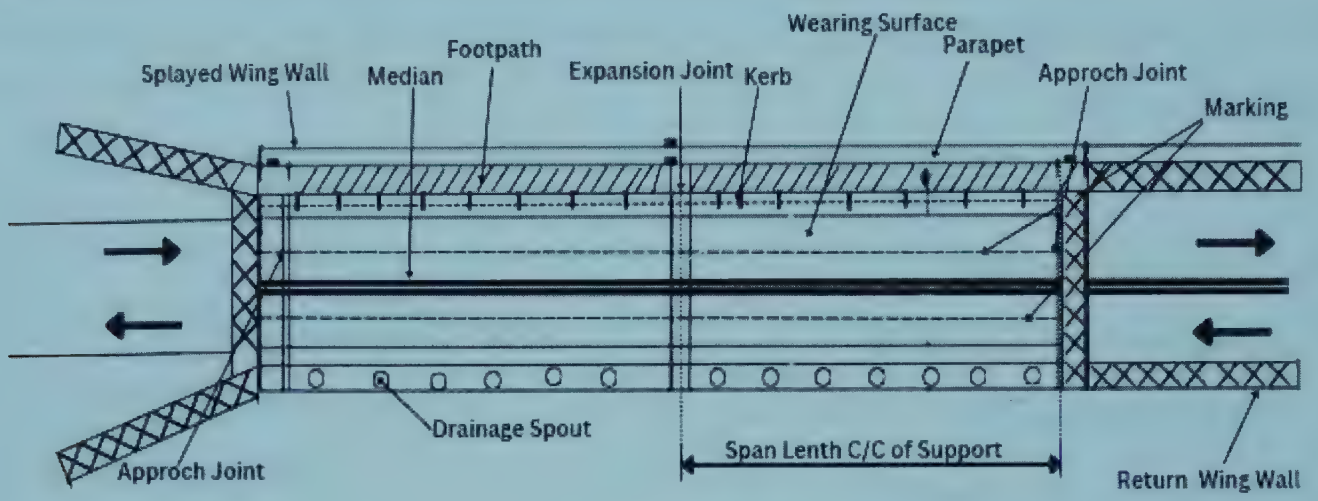
iv) **Foundations:** Foundations (Raft/Open/Pile/Well), Apron, Foundation protection etc.

v) **Superstructure:** Girders/Main beams/Cables/Arch, Cross beams/ Diaphragms/

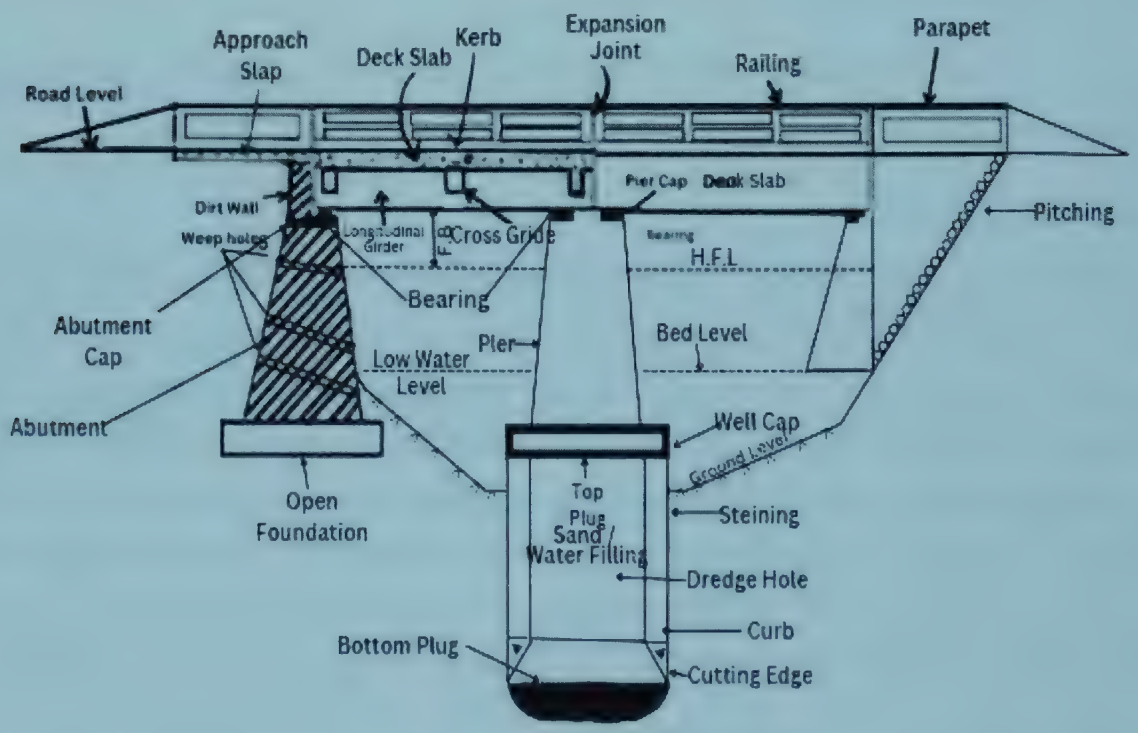
Stringers/Spandrel, Articulation, Deck slab, Cantilever slab, Joints

vi) **Appurtenances/Auxiliary Works:** Wearing Surface, Footpaths, Expansion Joints, Noise barriers, Anchorage etc., Median, Kerbs/Cornices, Light Posts, Drainage Spouts, Parapet/Railing/Guard Stones/Crash Barrier, Waterproofing System, Painting System, Utilities; and

vii) **Bearings:** Bearings, Bearing Seats/Caps, Earthquake Restraints, Anchor Bolts etc.



Plan



Elevation

Fig. 3.1 Bridge Components

These components may be regrouped as per convenience or requirement or more components can be added for better clarity. For example, metallic roller bearings may be further grouped in to top plate, bottom plate, rollers, anchor bolts etc.

The functions and other features of the major components of a road bridge are briefly discussed in subsequent sections:

3.3 Substructure

The substructure is the component of a bridge which includes all elements below the bearings and above the foundation. They may be Abutment, Dirt/Back wall, Weep holes, Wing walls, Abutment protection works, Pier/Pylon, Pier cap, Pier protection works, Bridge seat, etc. The purpose of the substructure is to transfer the loads from the superstructure to the foundation soil or rock. Substructure units function as both axially-loaded and bending members. These units resist both vertical and horizontal loads applied from the superstructure and roadway embankment. The loads are then distributed to the foundation of the bridge.

The primary components of a sub-structure are Piers and Abutments. The vertical support at each end of the bridge is called an Abutment, while other such intermediate supports are called Piers. This system of Piers and Abutments, in addition to carrying loads and forces transmitted to them from the superstructure, is in itself subjected to forces from wind, earthquakes, water currents, impact from floating trees and barges and earth pressure in case of abutments (since they retain the approach road embankment), etc. Piers and Abutments can be solid or hollow and in different shapes.

Abutments provide support for the ends of the superstructure and retain the roadway approach embankment **(Fig. 3.2)**. Piers and bents provide support for the superstructure at intermediate points along the bridge spans **(Fig. 3.3)**. In case of spill through abutments, the approach embankment is allowed to slope in front of the abutment and is protected by proper pitching with an adequate apron. Abutments normally have return walls at either end to retain the embankment of roadway. When they are constructed at some angle parallel to the approach road to embankment, these are called Wing Walls. They are considered as a part of sub-structure only if they are constructed as integral with abutments. They are constructed with separate foundations when constructed to the full height of the embankment. In some cases the wing walls are not for the full height and cantilever out from the abutment ends. These are called fly back returns and allow the earth to spill through on the sides as well. In some bridges RCC box returns are also provided behind the abutments.

Fig. 3.2 Abutment

Fig. 3.3 Pier

3.3.1 Abutments

Abutment may be (i) cantilever or full height abutment which extends from the grade line of the roadway or waterway below, to that of the road overhead **(Fig. 3.4)** or (ii) stub, semi-stub, or shelf abutment when located within the top most portion of the end of an embankment or slope - in the case of a stub, less of the abutment stem is visible than in the case of the full height abutment. **(Fig. 3.5)**, or (iii) spill-through or open abutment which consists of columns and has no solid wall, but rather is open to the embankment material **(Fig. 3.6)** - the approach embankment material is usually rock or (iv) integral abutment if superstructure and substructure are integral and act as one unit without an expansion joint or bearings **(Fig. 3.7)**. In this type of abutment, the relative movement of the abutment with respect to the backfill allows the structure to adjust to thermal expansions and contractions.

Fig. 3.4 Cantilever Abutment

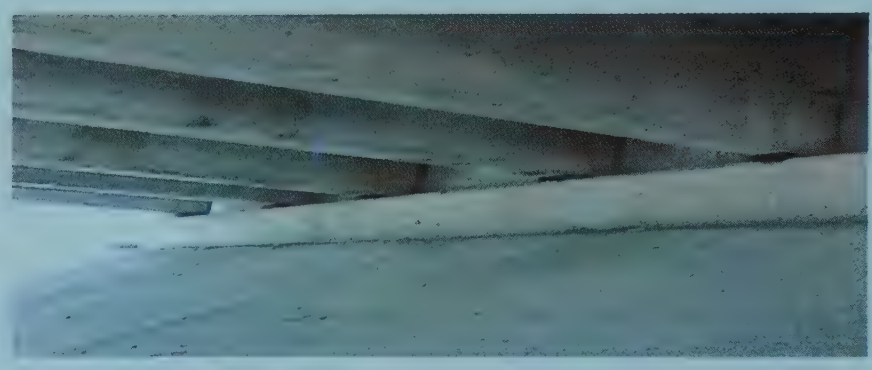


Fig. 3.5 Stub Abutment /Full Height Abutment

Fig. 3.6 Spill-Through or Open Abutment

Fig. 3.7 Integral Abutment

3.3.2 River Protection Works

Some bridges have to be provided with river protection works like guide bunds which are to be protected with stones of suitable size, protection to banks and protection to bed. These works need to be regularly inspected and damages should be rectified in time.

3.3.3 Piers and Bents

A pier has only one footing at each substructure unit (the footing may serve as a pile cap). A bent has several footings or no footing, as is the case with a pile bent.

There are four basic types of piers:

i) Solid shaft pier **(Fig. 3.8)**

ii) Column pier **(Fig. 3.9)**

iii) Column pier with web wall **(Fig. 3.10)**

iv) Cantilever or hammerhead pier **(Fig. 3.11)**

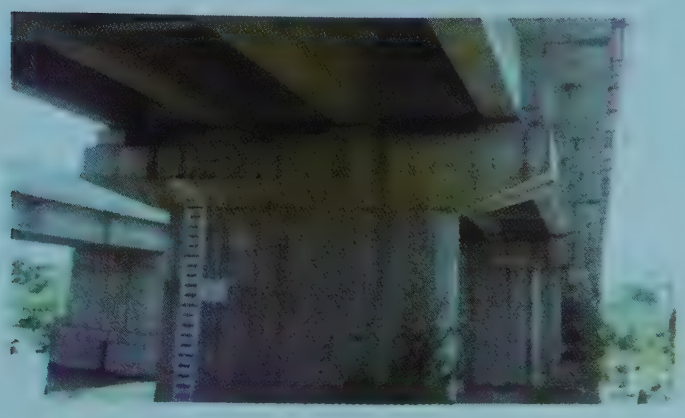


Fig. 3.8 Solid Shaft Pier

Fig. 3.9 Column Piers

Fig. 3.10: Column Pier with Web Wall and Cantilevered Pier Caps

Fig. 3.11 Cantilever or Hammerhead Pier

A bent is of two types namely, Column bent **(Fig. 3.12)** and Pile bent **(Fig. 3.13)**

Fig. 3.12 Column Bent

Fig. 3.13 Pile Bent

3.4 Foundation

All loads and forces coming from the superstructure and the sub-structure are to be transmitted to the earth stratum below the river bed or below other natural soil formation in such a manner that there is no unexpected settlement of the piers and abutments or damage due to scour during the design life of the bridge structure. The structural system which enables such a safe load-forces-transference to the soil strata from the substructure components is called foundation.

Foundations may be deep foundations or shallow foundations depending upon their depth below the bed being safely below. For deep foundations, normally well foundations are adopted while shallow foundations are mostly open foundations duly protected against scour by suitably designed pucca flooring, cut off walls, upstream and downstream flexible stone aprons. Pile foundations (bored, precast and driven, or cast in situ) are normally used in situations away from the river flow spread such as for flyovers or viaducts. However use of large-diameter bored piles is quite common for minor and medium bridges (and sometimes for long bridges also) where scour is not appreciable.

When span openings are small and individual open foundations are likely to either overlap or come too near to each other, a combined raft foundation is used e.g. in the case of a box culvert or a multiple box type bridge. Such a foundation too is normally protected on u/s and d/s by pucca flooring, cut off walls and aprons.

A few types of the foundations are shown in **Figs. 3.14** and **3.15.**

Fig. 3.14 Well Foundation

Fig. 3.15 Rectangular Pile

3.5 Superstructure

The structural system which supports the carriageway for movement of all vehicular traffic and footpaths, where required for use of pedestrians, for crossing over a river, or other impediments to the free flow of highway traffic, is called superstructure.

3.5.1 Structural Arrangement

The structural arrangement sustains all loads and forces coming from the traffic using the bridge and from other causes such as wind, earthquake, temperature changes (water currents in case of submersible bridges) and transmits the same to the ground (foundation) through the substructure. There are many different superstructure types such as: slabs, single web beams/girders, box beams/girders (multi-web), trusses, arches, rigid frames, cable-supported

bridges, movable bridges, floating bridges etc. However, there are four basic super structure forms which are shown in **Fig. 3.16**.

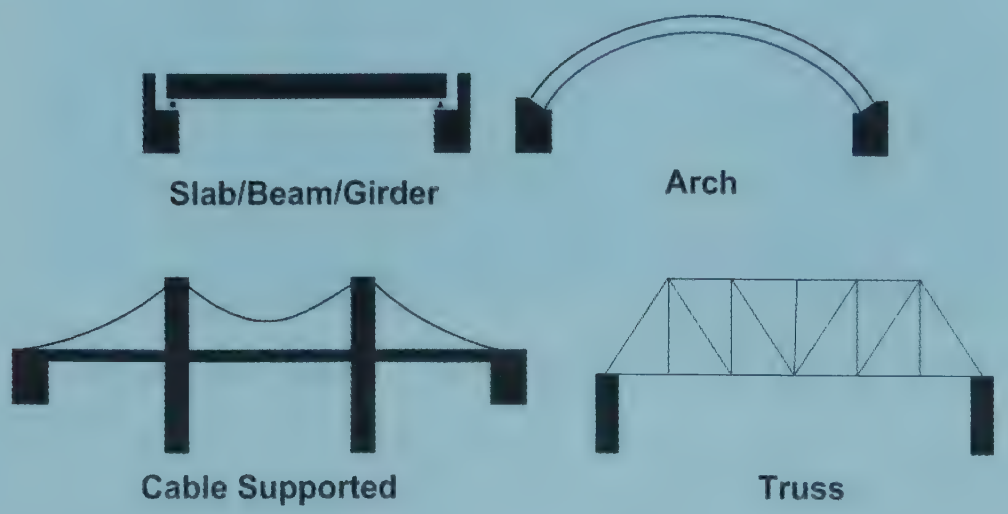


Fig. 3.16 Four Basic Bridge Types

3.5.2 Primary Members

The primary members in a superstructure typically consist of Girders, Floor beams Stringers, Trusses, Spandrel girders, Spandrel columns or bents, Arch ribs, Rib chord bracing, Hangers, Frame girder, Frame leg, Frame knee and Pin and hanger links. **Figs. 3.17**, **3.18** and **3.19** shows a typical floor system and main supporting members of a concrete bridge, a composite bridge and a steel arch bridge, respectively.

Fig. 3.17 Concrete Girders, Diaphragms and Deck Slab

Fig. 3.18 Floor System and Main Supporting Members of a Composite Bridge

Fig. 3.19 Main Supporting Members of a Steel Arch Bridge

Additionally, diaphragms for curved girders may also be considered as primary members. Vehicular live load is transmitted between the main supporting members through the diaphragms in a curved multi-girder arrangement.

3.5.3 Secondary Members

The secondary members do not normally carry traffic loads directly. Typical secondary elements are:

i) Diaphragms (see **Figs. 3.17. 3.18** and **3.20**)

ii) Cross or X-bracing (see **Fig. 3.21**)

iii) Lateral bracing

iv) Sway-portal bracing (see **Fig. 3.22**)

v) Pin and hanger assemblies - Through bolts, pin caps, nuts, cotter pins on small assemblies, spacer washers, doubler plates

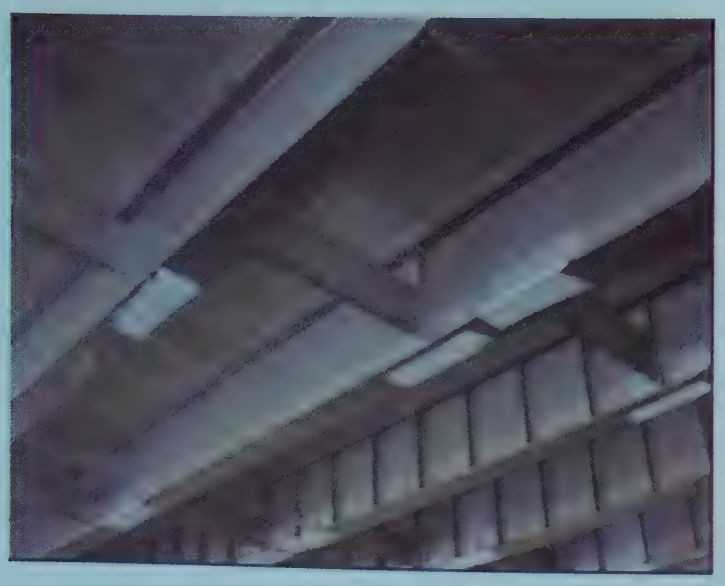


Fig. 3.20 Steel Diaphragms

Fig. 3.21 Cross or X Bracing

Fig. 3.22 Top Rail Bracing and Sway Bracing

3.5.4 Types of Superstructures

i) **Slab Bridges**: In slab bridges, loads from the slab are transmitted vertically to the substructure (**Fig. 3.23**)

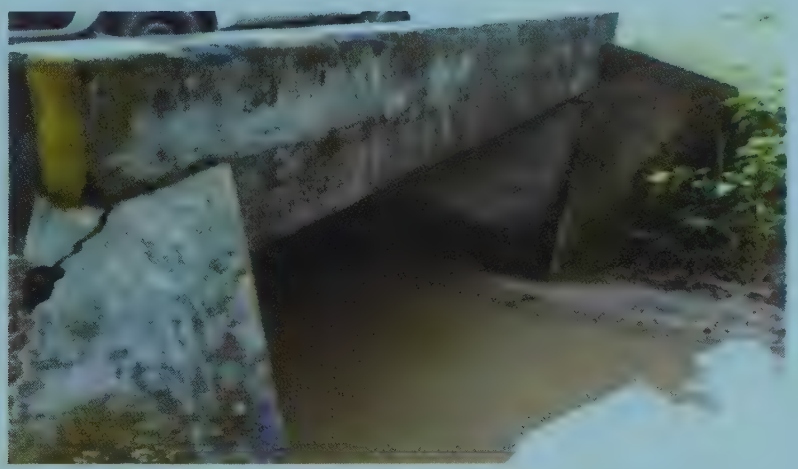


Fig. 3.23 Slab Bridge

ii) **Single Web Beam/Girder Bridges**

In the case of beam and girder bridges, loads from the superstructure are transmitted vertically to the substructure. **Figs. 3.24** and **3.25** show beam bridges and **Figs. 3.26**, **3.27** and **3.28** show girder bridges

Fig. 3.24 Beam Bridge

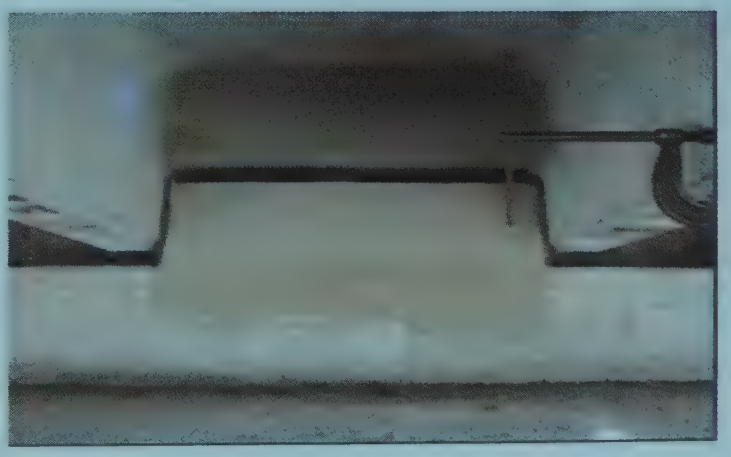


Fig. 3.25 Tee Beam Bridge

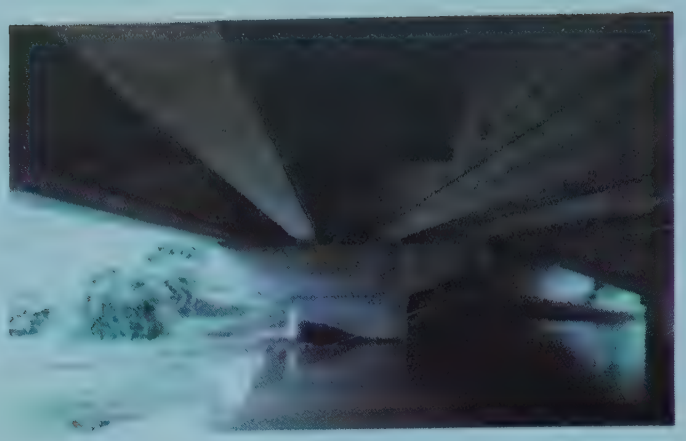


Fig. 3.26 Multi-Girder Bridge

Fig. 3.27 Curved Girder Bridge

Fig. 3.28 Box Girder Bridge

iii) Bridges with Truss Members

Truss members including chords, verticals and diagonals primarily carry axial tension and compression loads. Trusses can be constructed either from timber or steel (**Figs. 3.29** and **3.30**).

Fig. 3.29 Deck Truss Bridge

Fig. 3.30 Through Truss Bridge

iv) Arch Bridge

In the case of arch bridges, the loads from the superstructure are transmitted diagonally to the substructure. True arches are in pure compression. Arch bridges can be constructed from timber, concrete, or steel (**Figs. 3.31** and **3.32**).

Fig. 3.31 Deck Arch Bridge

Fig. 3.32 Through/Tied Arch Bridge

v) Rigid Frames

Rigid frame superstructures are characterized by rigid connections between the horizontal girder and the legs. This connection allows the transfer of both axial forces and moments into vertical or sloping elements, which may be classified as superstructure or substructure elements depending on the exact configuration. Similar to beam/girder or slab configurations, rigid frame systems may be multiple parallel frames or may contain transverse floor beams and longitudinal stringers to support the deck (**Fig. 3.33**).

Fig. 3.33 Rigid Frames

vi) Cable-Supported Bridges

In the case of cable-supported bridges, the superstructure loads are resisted by cables which act in tension. The cable forces are then resisted by the substructure anchorages and towers. Cable-supported bridges can be either suspension or cable-stayed (**Figs. 3.34** and **3.35**).

Fig. 3.34 Suspension Bridge

Fig. 3.35 Cable stayed bridge

vii) Movable Bridges

The purpose of a movable bridge is to provide the appropriate channel width and under clearance for passing water vessels when fully opened. Movable bridges can be classified into three general groups i.e. Bascule Bridge (see **Fig. 3.36**), Swing Bridge (see **Fig. 3.37**) and Lift (see **Fig. 3.38**)

Fig. 3.36 Bascule Bridge

Fig. 3.37 Swing Bridge

Fig. 3.38 Lift Bridge

viii) Floating/Pontoon Bridges

Although uncommon, some bridges that are not supported by a substructure Instead, they are supported by water. The elevation of the bridge will change as the water level fluctuates **(Fig. 3.39)**.

Fig. 3.39 Floating/Pontoon Bridge

3.5.5 Types of Decks

i) **Integral & Non-Integral Deck:** The deck is that component of a bridge to which the live load is directly applied. The purpose of the deck is to provide a smooth and safe riding surface for the traffic utilizing the bridge. The function of the deck is to transfer live loads and dead loads off and on the deck to other bridge components commonly referred to as the superstructure. However, on some bridges (e.g., a concrete slab bridge), the deck and the superstructure are one unit which distributes the live load directly to the substructure. Depending on the function, the decks can be one of two types namely

Composite Decks: Which act together with their supporting members and increase superstructure capacity (**Fig. 3.40**)

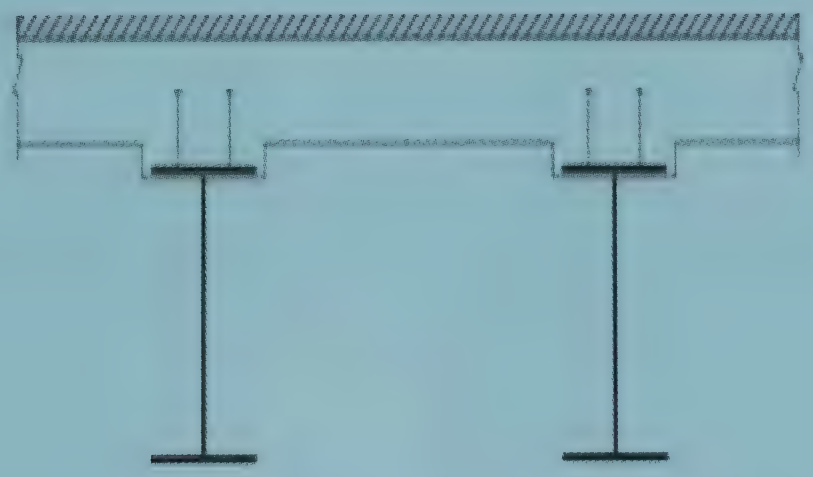


Fig. 3.40 Composite Decks and Steel Superstructure

Non-composite Decks: These are not integral with their supporting members and do not contribute to structural capacity of the superstructure.

ii) **Steel Decks:**

Steel decks are decks composed of either solid steel plate or steel grids (see **Fig. 3.41**). There are four common types of steel decks namely, Ortho-tropic Deck, Buckle Plated Deck, Corrugated Steel Flooring and Grid Deck- Open, Filled, or Partially Filled.

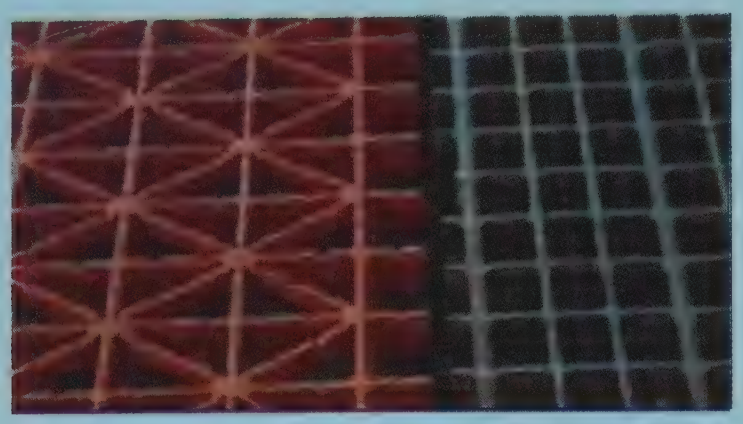


Fig. 3.41 Steel Grid Deck

iii) **Fibre Reinforced Polymer (FRP) Decks**

With the advent of technological development, innovative material such as fibre-reinforced polymer (FRP) bridge decking has begun replacing existing highway bridge decks. Though FRP material is more expensive than conventional bridge materials such as concrete, it has several advantages. They are lighter weight for efficient transport, better resistance to earthquakes and easier installation. FRP bridge decking is also less affected by water and de- icing salts, which corrode steel and deteriorate, concrete (**Fig. 3.42**).

Fig. 3.42 Fibre Reinforced Polymer (FRP) Deck

3.5.6 Expansion Joints/Deck Joints

Between simply supported spans or units of a continuous span system and at the ends of the superstructure adjacent to the dirt wall of the abutments, the gaps are bridged by properly designed bridging arrangements which besides protecting the exposed edges of the deck slab and ensuring smoother rideability, allow expansion/contraction of the superstructure. These components of the deck-furniture of a bridge are called expansion joints.

Design of the expansion joints varies with the extent of movements. Proper design, adequately strong and leak-proof construction, correct installation and regular maintenance of the expansion gap are essential requirements for ensuring satisfactory performance of expansion joints. Badly leaking, loose and knocking, dirt clogged or broken or dislodged expansion joints are not desirable for a bridge. Even the best of such joints installed under strict supervision of the suppliers require periodical replacement and hence the need for proper inspection at regular intervals. Leaking expansion joints have been the cause of serious distress due to corrosion of pre-stressing tendons and malfunctioning of the bearings. Hence, during inspection of bridges, expansion joints and bearings need special attention.

The primary function of a deck joint is to accommodate the expansion, contraction and rotation of the superstructure. The joint must also provide a smooth transition from an approach roadway to a bridge deck, or between adjoining segments of bridge deck.

There are six categories of deck joints:

i) Strip Seal Expansion Joints **(Fig. 3.43)**

ii) Compression Seal Joints **(Fig. 3.44)**

iii) Finger Type Joint **(Fig. 3.45)**

iv) Slab Seal Joint

v) Modular Joints

vi) Asphalt Plugged Joints

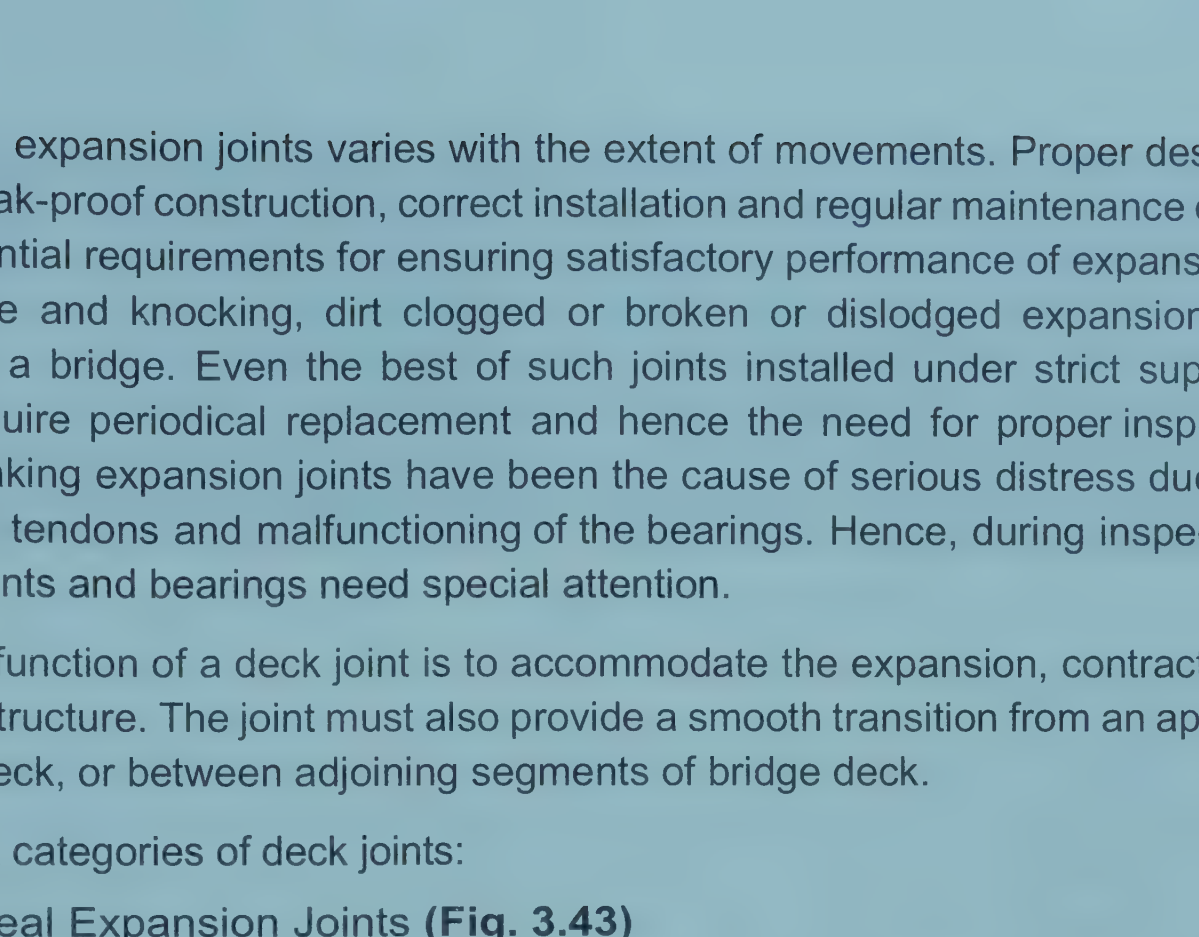


Fig. 3.43 Strip Seal Expansion Join

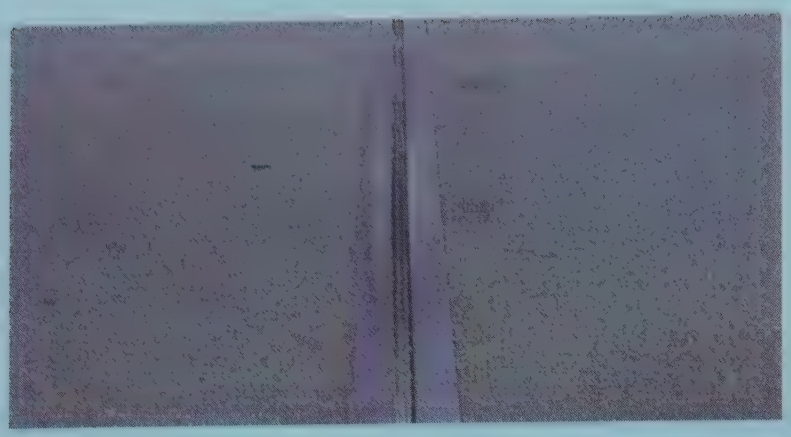


Fig. 3.44 Armoured Compression Seal in Place

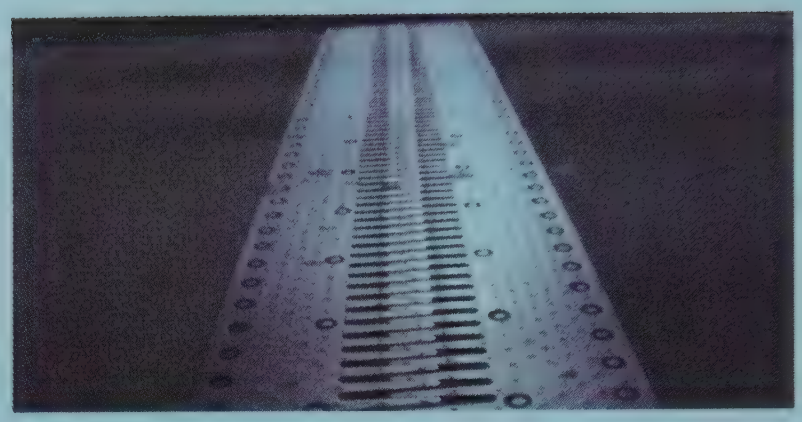


Fig 3.45 Finger Plate Joint

3.5.7 Deck Drainage System

Nothing can be more annoying to the users, whether in vehicles or on a foot, than a waterlogged carriageway. Worse still is the resulting likely structural distress due to the presence of moisture for long durations. Riding surface can have in-adequate cross slope or non-functioning drainage outflow system. These problems also need proper identification during inspection. Again, water flowing out of the drainage spouts should not be allowed to fall on the supporting main girders or cross girders but should be led or deflected away from these.

A properly designed drainage system ensures that water from various well-spaced drainage outlets is collected into a longitudinal pipe along the span and then brought down at pier locations so as to discharge into the stream or into the surface drainage system in case of flyovers.

3.5.8 Wearing Course

Deck-slab forming the main structural component of the carriageway is provided with a suitable overlay of adequate thickness either in good quality high strength concrete or in layers of graded bituminous construction. This additional covering layer laid in proper longitudinal and transverse profile is called the wearing course and takes on all the frontal attack of the moving heavy vehicles and that of the natural elements. A bridge may have one of the following wearing surfaces:

i) Timber Planks – running boards

ii) Bituminous

iii) Concrete

iv) Steel Plate (FOBs)

The Concrete decks may have wearing surfaces of (a) Concrete – Latex Modified Concrete (LMC), (b) Low Slump Dense Concrete (LSDC), (c) Light Weight Concrete (LWC), (d) Fibre Reinforced Concrete (FRC), (e) Micro-silica Modified Concrete, (f) Bituminous (**Fig. 3.46**) and (g) Polymers - epoxy, polyester, methyl methacrylate Steel decks may have wearing or riding surfaces of (a) Serrated Steel, (b) Concrete, (c) Asphalt and (d) Polymers.

Fig. 3.46 Bituminous Wearing Course

Deterioration of wearing course affects riding quality and can lead to distress in the structural deck slab and main supporting members from water leaking into the deck through cracks and pot holes, especially when there is no waterproof layer interposed. Therefore, proper attention to assess the serviceability of the wearing course during inspection assumes importance. Any water layer locked in between the wearing course and the structural deck-slab is not desirable. Water is constantly pumped in through pressure of heavy moving vehicles and being often contaminated especially in marine environments can be a dangerous source of distress in concrete and reinforcement.

3.5.9 Bearings

Bridge bearing is an element which provides an interface between the superstructure and the substructure and transfers the traffic loading and the weight of the bridge from the superstructure to the substructure. Bearings also allow the bridge to expand and contract, as well as allow for rotation of the deck as they deflect under live loads. Some bearings act as fixed bearings, which anchor the superstructure to the substructure (only allowing rotation), while the others allow for expansion and contraction. The ones that allow for expansion and contraction are sliding, rocker, or roller bearings. The bearings used in Indian bridges are made of steel, neoprene (Elastomeric) or PTFE.

Bearings can be sliding bearings, reinforced elastomeric pads, roller and rocker bearings in steel and pot bearings. For submersible bridges and for bridges in earthquake prone zones stoppers are provided against any transverse dislodging movement of the superstructure.

These are concrete blocks monolithic with the pier or pier cap, steel bars or girders embedded in pier and projecting above.

For a single span or simply supported multi-span system one bearing is a fixed bearing and the other permits movement. For continuous spans system expansion or contraction is allowed with one end fixed in position and movements being allowed at all others.

Depending on the function and capacity, there are six bearing types that are utilized to accommodate superstructure movement and rotation. They are as follows:

i) Steel Bearings

ii) Elastomeric Bearings

iii) Hinge Bearings

iv) Pot Bearings

v) Disk Bearing and

vi) Spherical & Cylindrical Bearings

A bridge bearing can be normally categorized into four basic elements (**Fig. 3.47**) i.e. Sole Plate, Bearing Device, Top Plate and Anchor Bolts.

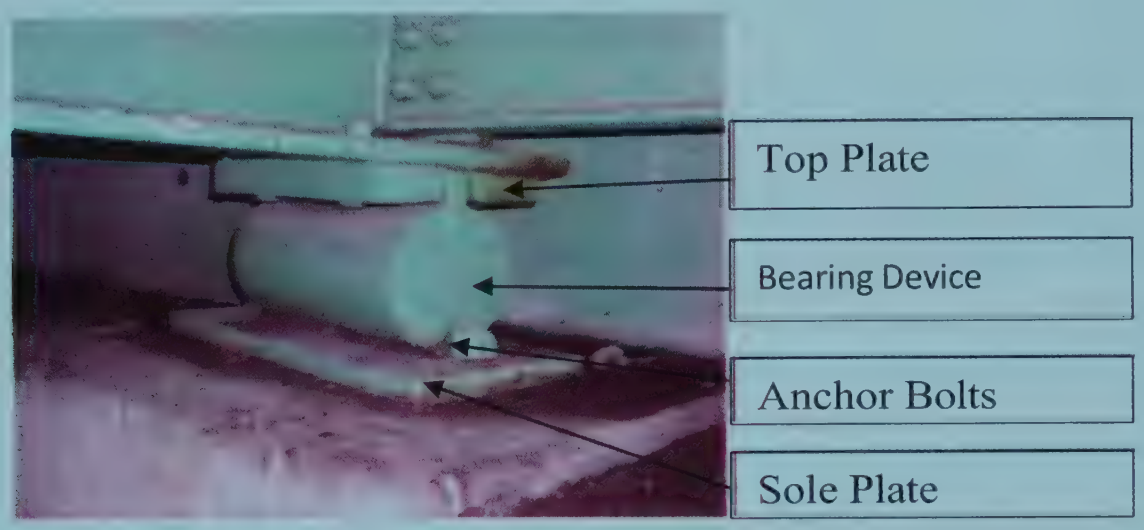


Fig. 3.47 Steel Rollers Bearing showing four Basic Elements

3.5.10 Railings/Parapets/Crash Barriers and Footpath (Precast) Slabs and Kerb

All these items form a part of the carriageway and are normally constructed after the main load bearing structural system of the span has been completed. Since these are essential for the safety of vehicles and pedestrians, their condition requires to be as meticulously inspected as of the main structural components. Railings may have an open design consisting of vertical posts and horizontal members, parapets and crash barriers and solid kerbs which act as an extreme edge guide for the vehicular traffic and is also continuous and made monolithic with the deck slab (except in the case of submersible bridges, where kerbs are discontinuous with gaps in between and railings.

3.5.11 Steel Bridge Components

There are two types of iron members: cast iron and wrought iron. Cast iron is formed by casting, whereas wrought iron is formed by forging or rolling the iron into the desired form.

Cast Iron

Historically, cast iron preceded wrought iron as a bridge material. The method of casting molten iron to form a desired shape was more direct than forging wrought iron.

Casting allowed iron to be formed into almost any shape. However, because of cast iron's brittleness and low tensile strength, bridge members of cast iron were best used to carry axial compression loads. Therefore, cast iron members were usually cylindrical or box-shaped to efficiently resist axial loads.

Wrought Iron

In the late 1800's, wrought iron virtually replaced the use of cast iron. The two primary reasons for this were that wrought iron was better suited to carry tensile loads and advances in rolling technology made wrought iron shapes easier to obtain and more economical to use. Advances in technology made it possible to form a variety of shapes by rolling, including Rods and wire, Bars, Plates, Angles, Channels and I-Beams

Steel Shapes

Due to their strength, steel bridge members are used to carry axial forces as well as bending forces. Steel shapes are generally either rolled or built-up.

Rolled steel shapes commonly used on bridges include **(Fig. 3.48)** Bars and Plates, Angles, Channels, Beams (I-beams) and W-Beams (Wide flange I-beams. Angles, bars and plates are commonly connected to form bracing members **(Fig. 3.49)**.

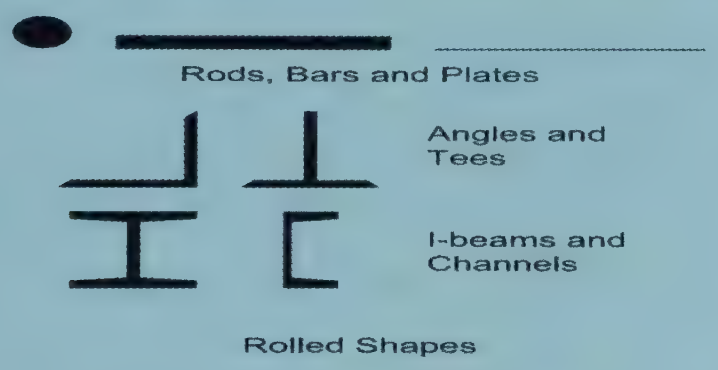


Fig. 3.48 Common Rolled Steel Shapes

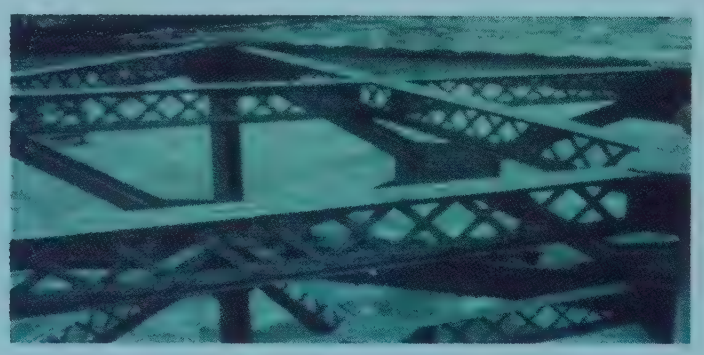


Fig. 3.49 Bracing Members made from Angles, Bars and Plates

Channels are squared-off C-shaped members and are used as diaphragms, struts, or other bracing members. Beams are I-shaped sections used as main load-carrying members.

Built-up Shapes

Built-up shapes offer a great deal of flexibility in designing member shapes. As such, they allow the bridge engineer to customize the members for his particular need. Built-up shapes are fabricated either by riveting, bolting or welding techniques **(Figs. 3.50, 3.51, 3.52 & 3.53).**

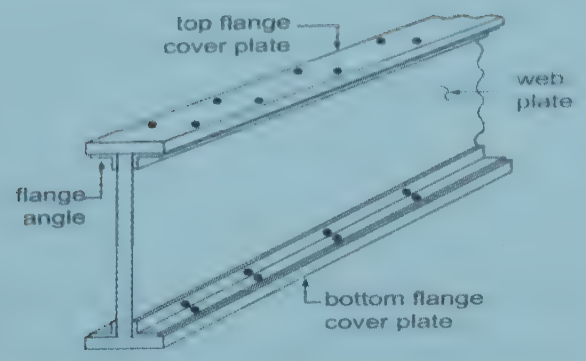


Fig. 3.50 Riveted Plate Girders

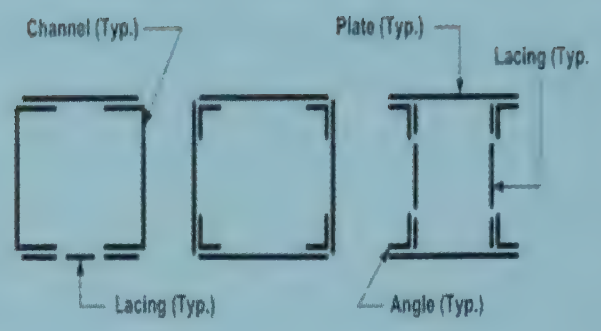


Fig. 3.51 Riveted Box Shapes

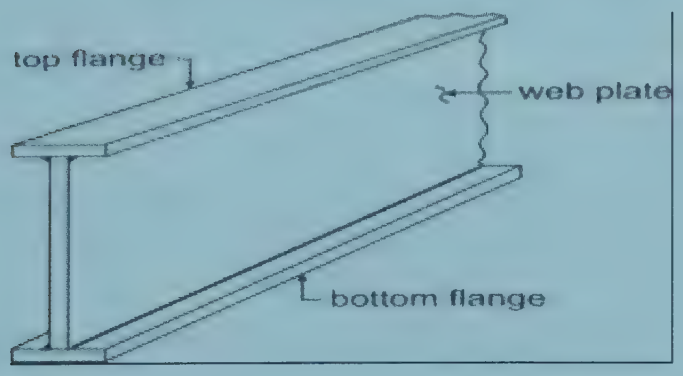


Fig. 3.52 Welded I-Beam

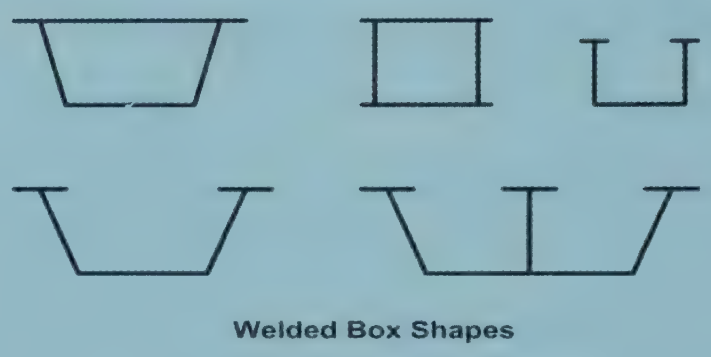


Fig. 3.53 Welded Box Shapes

Cables

Steel cables (**Fig. 3.54**) are tension members and are used in suspension, tied arch and cable stayed bridges. They are used as main cables and hangers of these bridge types (**Figs. 3.34** & **3.35**).

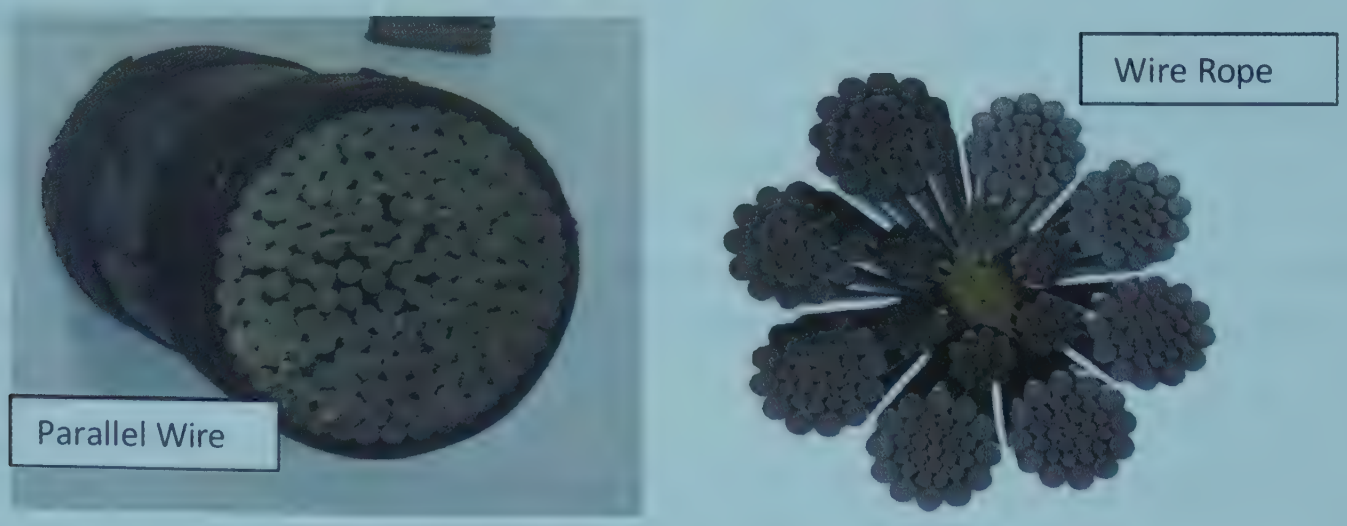


Fig. 3.54 Cable Cross Sections

Connections

Rolled and built-up steel shapes are used to make stringers, floor beams, girders, trusses, frames, arches and other bridge members. These members require structural joints, or connections, to transfer loads between members. There are several different types of bridge

member connections which include Pin, Riveted, Bolted, Welded, Pin and hanger assemblies, Splice connections etc.

i) Pin Connections

Pins are cylindrical bars produced by forging, casting, or cold-rolling. The pin sizes and configurations are as follows (**Fig. 3.55**)

a) A small pin, 30-100 mm in diameter, is usually made with a cotter pin hole at one or both ends

b) A medium pin, up to 250 mm in diameter, usually has threaded end projections for recessed retainer nuts

c) A large pin, over 250 mm in diameter, is held in place by a recessed cap at each end and is secured by a bolt passing completely through the caps and pin

Pins are often surrounded by a protective sleeve, which may also act as a spacer to separate member elements. Pin connections are commonly used in eye bar trusses, hinged arches, pin and hanger assemblies and bearing supports (**Fig. 3.56**).

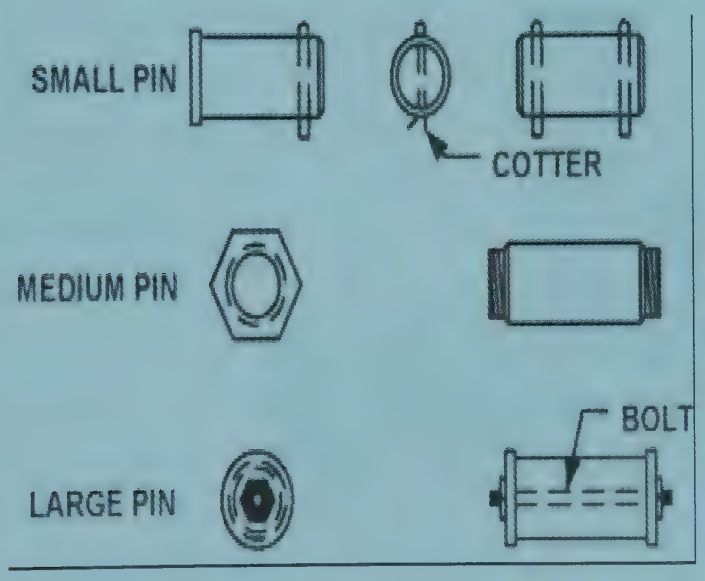


Fig. 3.55 Sizes of Bridge Pins

Fig. 3.56 Pin-Connected Eye bars

ii) Riveted Connections

The rivet was the primary fastener used in the early days of iron and steel bridges. High strength bolts replaced rivets. The standard head is called a high-button or acorn-head rivet. Flat-head and countersunk-head rivets were also used in areas of limited clearance, such as a hanger connection (**Fig.3.57**)

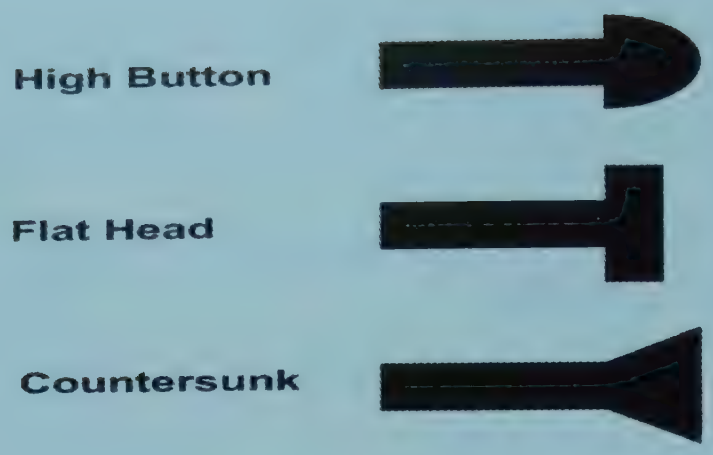


Fig. 3.57 Types of Rivet Heads

iii) Bolted Connections

The economic and structural advantages of bolts over rivets led to their rapid use by bridge engineers. Bridges constructed in the late 1950"s may have a combination of riveted (shop) and bolted (field) connections (**Fig. 3.58**). Structural fasteners shall conform to IRC:22, IRC:24 and IRC:SP:104.

Fig. 3.58 Shop Rivets and Field Bolts

iv) Welded Connections

Pins, rivets and bolts are examples of mechanical fasteners. A welded connection is not mechanical but rather is a rigid one-piece construction. A properly designed and executed welded joint, in which two pieces are fused together, is as strong as the joined materials.

Similar to mechanical fasteners, welds are used to make structural connections between members and also to connect elements of a built-up member. Welds have also been used in the fabrication and erection of bridges as a way to temporarily hold pieces together prior to field riveting, bolting, or welding. Small temporary erection welds, known as tack welds, can cause serious fatigue problems to certain bridge members (**Fig. 3.59**). Welding is also used as a means of sealing joints and seams from moisture.

Fig. 3.59 Fatigue Problems at Tack Welds

v) Pin and Hanger Assemblies

A pin and hanger assembly is used to connect two plate girders of a bridge. These assemblies are used to provide an expansion joint in the bridge. One beam (the anchor span) is set on a pier with a short section cantilevered out toward the next pier. The other (the suspended span) begins underneath the anchor span and has its far end resting on the next pier. The beams have holes directly above each other. The two holes are connected using hangers, a pair of connecting plates sandwiching the bridge girders. **Fig. 3.60** shows a typical pin and hanger assembly.

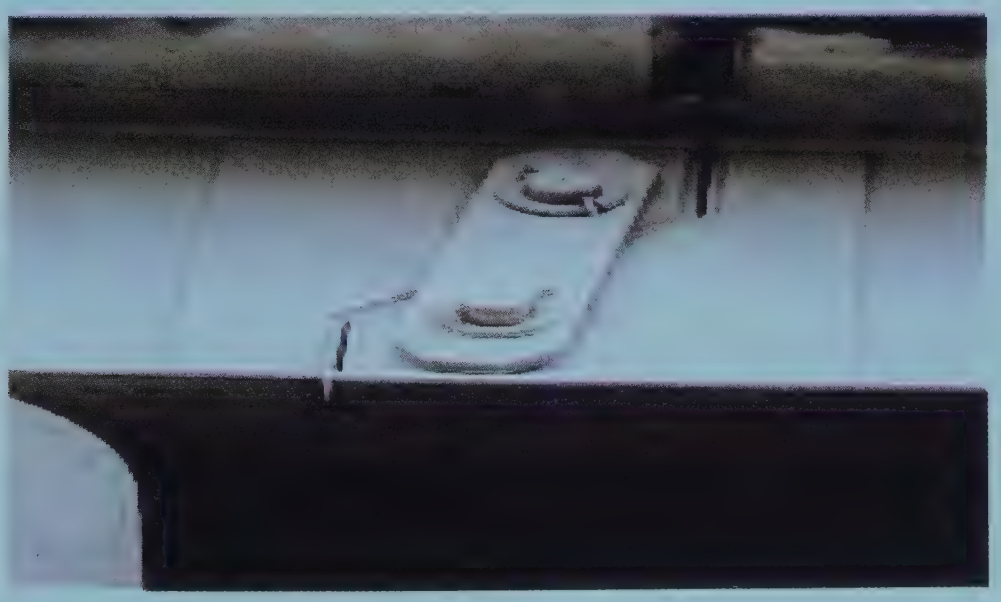


Fig. 3.60 Pin and Hanger Assembly

vi) Splice Connections

A splice connection is the joining of two sections of the same member, either in the fabrication shop or in the field. This type of connection can be made using rivets, bolts, or welds. Bolted splices are common in multi-beam superstructures due to the limited

allowable shipping lengths (**Fig. 3.61**). Shop welded flange splices are common in large welded plate girders and long truss members.

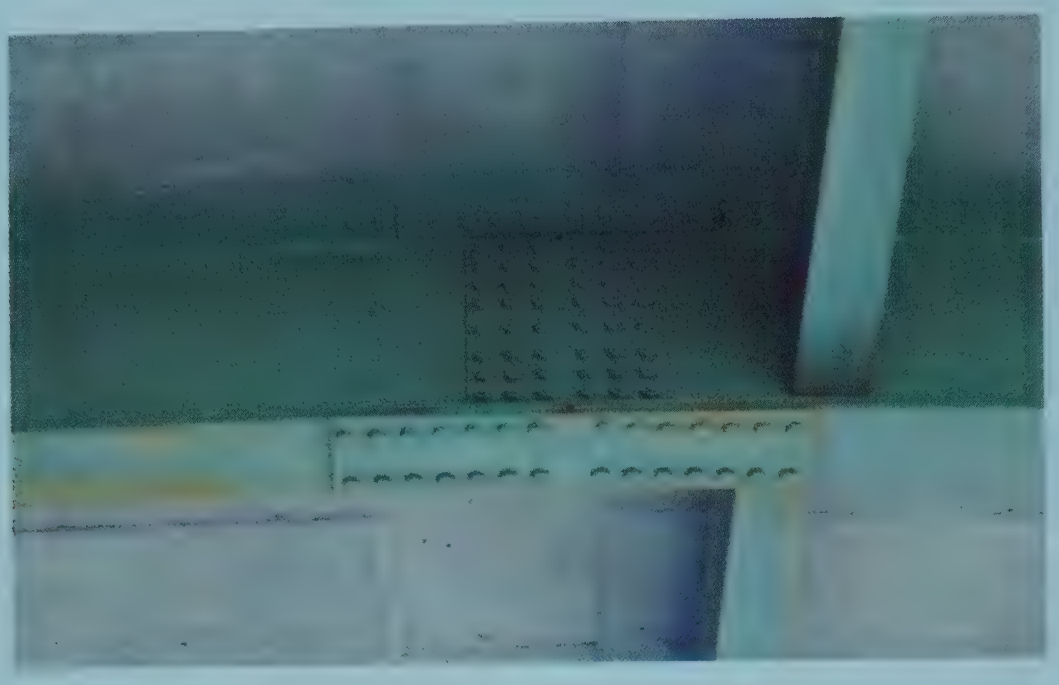


Fig. 3.61 Bolted Field Splice

3.6 Masonry Bridge Components

Masonry Bridges are constructed by using bricks or stones. These are generally constructed for short spans and in low depth canals. Salient components of a typical masonry bridge are shown in **Fig. 3.62** and are defined.

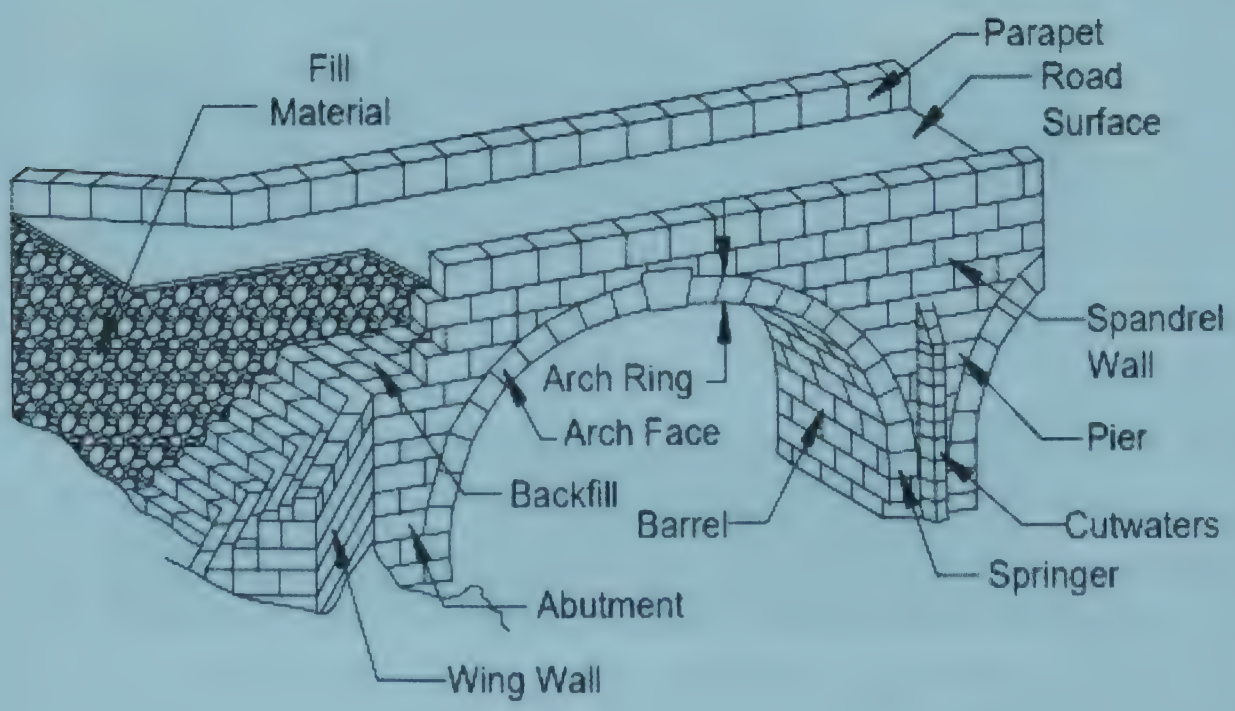


Fig. 3.62 Salient Components of a Typical Masonry Bridge

Abutment: Part of a structure which supports the end of a span or accepts the thrust of an arch often supports and retains the approach embankment.

Arch: A curved structure which supports a vertical load mainly by axial compression.

Arch barrel: The inner surface of an arch extending the full width of the structure.

Arch ring: An outer course of stone forming the arch, made of a series of voussoirs. An archivolt is an arch ring with decorating moldings.

Centering: Temporary structure or false work supporting an arch during construction.

Extradosed: The outer exposed curve of an arch defines the lower arc of a spandrel.

Eye bar: A structural member having a long body and an enlarged head at each end. Each head has a hole through which a pin is inserted to connect to other members.

Fill: Earth, stone or other material used to raise the ground level, form an embankment or fill the inside of an abutment, pier or closed spandrel.

Finial: A sculpted decorative element placed at the top of a spire or highpoint of a structure.

Fixed arch: A structure anchored in its position compare to hinged arch.

Keystone: The uppermost wedge-shaped voussoir at the crown of an arch which locks the other voussoirs into place

King Truss: Two triangular shapes sharing a common center vertical member; the simplest triangular truss system compare to queen truss.

Spandrel: The roughly triangular area above an arch and below a horizontal bridge deck. A closed spandrel encloses fill material. An open spandrel carries its load using interior walls or columns.

Springer: The first voussoir resting on the impost of an arch.

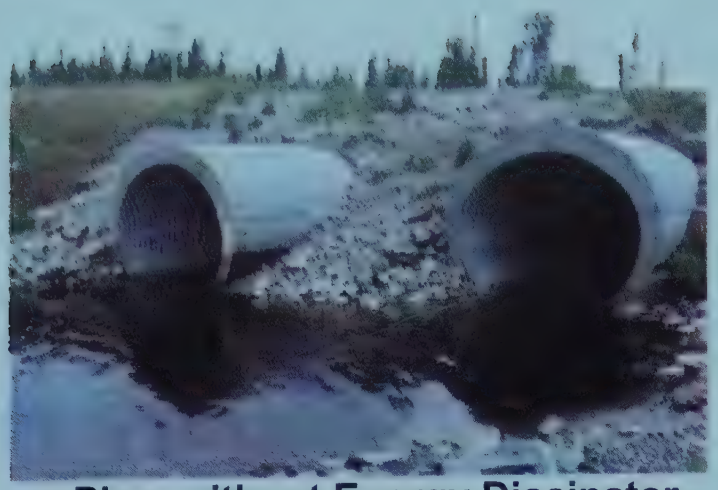
Spring line: The place where an arch rises from its support; a line drawn from the impost

Tied Arch: An arch which has a tension member across its base which connects one end to the other.

Trussed Arch: A metal arch bridge which features a curved truss.

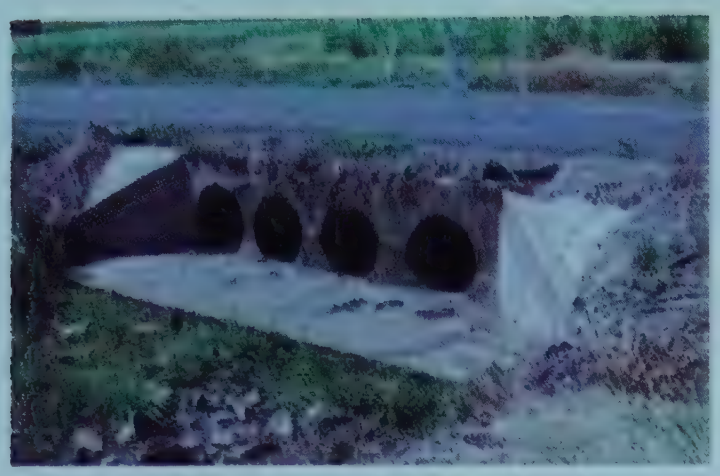
3.7 Culverts

Culverts are cross-drainage works with total length up to 6 m between outer faces of wall. They may be of various shapes such as pipe/box/arch, etc. and constructed precast or cast in-situ. Various types of culverts are shown in **Fig. 3.63**



Pipe without Energy Dissipator

Pipe with Energy Dissipator



Pipe with Apron & Wing Wall

Single Circular-Stone Arch

Twin Segmental-Brick Arch

Triple Elliptical-Stone Arch

Triple Box Type-Concrete

Quadruple Box Type-Concrete

Rectangular Multiple Apron

Rectangular Single with Wing wall & apron

Rectangular Double with retaining wall

Circular Multiple-Over Pier-Stone

Fig. 3.63 Different Types of Culverts

CHAPTER 4
INVENTORY OF BRIDGES

4.1 Basis of Inventory

Inventory of bridges is paramount in managing them. Inventory shall contain all the administrative and technical data representing the bridge. This will enable the bridge owners to have a centralized as well as local database from which various reports can be prepared and be used for both the administrative and technical purposes. The inventory is also necessary for carrying out the condition survey of bridges. As far as the inventory is concerned it is necessary to collect and preserve as much information as possible. Once it is collected no further inventorisation is required. In view of this there shall be no restriction to be put on the data to be inventorised. A unified inventory fields are suggested and shall be used for all the bridges including culverts. Inventory should not to be confused with condition survey which prescribes the present status of bridge components.

4.1.1 Structural Number

The relevant guidelines for State/UT codes, chainages, numbering etc. of the Ministry and IRC:7-2017 shall be refereed to for the numbering of culverts, bridges and tunnels at site. The inventory and the various inspection reports of structures shall be stored against unique structural number prescribing Name of the State/UT, Road Type & No, Type of The Structure, Serial Number and Location as below:

APNH044C0001@11.5

State/UT: Andhra Pradesh; Road Type: NH & Its Number 44; Type of the Structure: Culvert; Serial No. is 1 and it is at km 11.5

4.2 Bridge Inventory Data

The following inventory data may be collected for bridges as per following classifications along with the photographs but not limited to:

- Administrative/General Data
- Technical Data
- Geometric Data
- Hydraulic Data
- Traffic Data
- Geotechnical Data
- Environmental Data
- Loading
- Structural Design & Drawing Data

- Land Details
- Type of the Culvert: RCC Hume Pipe/RCC Slab/ Stone Slab/RCC Box-Cell/Arch etc.
- Type of the Material: Concrete/Stone/Brick/Steel etc.
- Grade of Steel/Concrete Location/Chainage
- Span Length
- No. of Pipe/Slab/Cell/Rows etc.
- Diameter of Pipe/Width of Cell
- Roadway Width
- Depth of Cushion/Thickness of Slab
- Type of Founding Strata
- Bearing Capacity of Soil
- Year of Construction

Complete inventory of bridges and culverts shall be carried out in detail as per data fields given in **Appendix-I** and **Appendix-II** Respectively.

4.3 Inventory Methodology

Inventory shall have to be done at both the office and site. Exact nomenclature and measurements of all the components of a bridge are to be done so as to avoid future expenditure on inventory. If design data and drawings are not available, especially for the old bridges, site inventory has to be done by visual inspection and detailed measurements of the dimensions of all the bridge components shall be carried out at the site and, photographs collected / drawings shall be made if possible and saved for future use. IT tools may also be developed for collecting or storing the inventory data. It may also be supplemented by advanced techniques like GPR, Lidar, Drones and Satellites etc.

Collection of available inventory data and previous inspection and maintenance records is prerequisite for bridge inspection.

4.4 Records and Reports

The prime need for any bridge inspection and maintenance operation is a complete, accurate and up- to-date record of the bridge. The utility of field investigations is served little without the maintenance of proper records. The records should therefore provide a complete history of the structure right from the stages of construction. The records should also contain information of all CD structures/Culverts on all type of roads.

Copies of records shall also be kept at concerned local sections to the office of head of the department/Agency, in both the soft and hard copy formats to ensure their availability at least

one place, so that, in future, if up-gradation of such roads to higher level is taken up, they could be used.

4.4.1 Bridge Register

For maintenance of records of bridges, a bridge register/inventory as indicated at **Appendix-I** shall be used. One bridge register may include the reports in respect of several bridges. However, for each bridge there must be two reports i.e. (i) Original Bridge Report and (ii) Inspection Report(s).

The reports prepared embracing all the important points as detailed above should be complete, clear and concise so that they could be easily understood without any ambiguity. These reports shall be maintained by the concerned Works Division so as to make them available to the inspecting officers.

4.4.2 Original Bridge Reports

In case of newly constructed bridges, the original bridge report shall be prepared on the basis of as built completion drawings supplemented with detailed condition report before opening to the traffic. The site inspection may be done for verification wherever necessary. In case of old bridges where sufficient data is not available, an investigation should be undertaken for compiling the same. The items to be covered in the Original Bridge Report shall be those listed in the Proforma given at **Appendix-III.** In addition to the data field mentioned in **Appendix-I** brief report shall be made in text form indicating salient features of the bridge. Some of the items are elucidated here under for clarification and guidance.

i) **Soil Characteristics:** The type of soil at the founding strata, its safe bearing capacity, whether the soil is susceptible to meandering or scour or not etc. shall be included. For major bridges indicate the different type of-soil strata based on bore hole data for the entire width of the river at the bridge site.

ii) **Foundations:** The type of foundations like well, piles, open, etc., below abutments and piers separately and give dimensions of all components like length, well diameter, staining thickness, pile diameter, spacing and arrangement of piles, dimensions of open foundations, etc. shall be indicated. Also indicate whether endangering of foundations due to excessive scour or settlement has taken place in the past, any other special feature like sulphate attack, degradation, aggradation of bed, etc.

iii) **Sub-structure:** Mention type of substructure, *e.g.,* masonry, plain cement concrete, reinforced cement concrete, pre-stressed cement concrete, extrados cable stayed or suspension bridge, etc. and broad dimensions of the substructure components as well as of the wing walls and RCC returns, etc. shall be included. Mention any special features like past incidents of corrosion and remedial measures thereof, damage due to impact of floating bodies, etc.

iv) **Bearings:** The type of bearings, material, brief details like the design load, exact dimensions of the bearings, location of lifting points, procedure for lifting, replacement of

the bearings if done and the date, last date of greasing for metallic bearings, etc. should be given.

v) **Superstructure:** Indicate the type of superstructure like steel composite, reinforced cement concrete, pre-stressed cement concrete, steel, masonry arch etc. Give brief details of the various components (explained by sketch), method of pre-stressing, cross pre-stressing used or not, any other special features etc.

vi) **Protective Works:** The type of protective works and the broad dimensions of the layout, height slope and thickness, etc. (explained by sketch) should be given. Bed protection details such as the type of bed protection and the thickness of bed flooring, depth of cut off walls, width and thickness of launching aprons on upstream and downstream also should be given.

vii) **Special Features**: Special features like Seismic Stoppers/arrestors, Bridge Approaches, Utilities and Bridge Numbers, Waterway, Expansion joints, Drainage spouts, Vent holes, Wearing Course, Kerb, Footpath, Crash barrier, Parapet and other important items like under water units shall be included.

Modified Reports

In case of bridges which have been substantially altered by widening or strengthening or by some other manner extensively modifying the existing conditions, these should be incorporated in the original report in red indicating clearly the modifications thereon with date. The information contained in the original/modified bridge report shall be utilized to complete the summary of bridge.

Inspection Reports

Inspection reports shall be prepared for all structures and maintained along with original bridge reports and inventory for not only its service life but archive shall be maintained even after it is reconstructed or abandoned as per structural number.

CHAPTER 5

DISTRESS IN BRIDGE COMPONENTS AND CONDITION STATES

5.1 List of Distresses

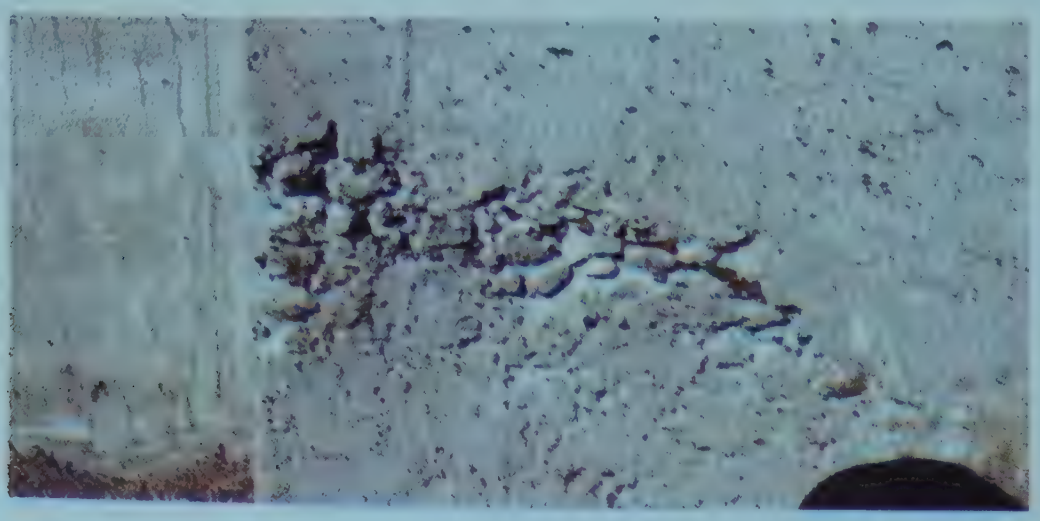
Deterioration is a complex phenomenon and it may not possible to include all the distress types in to one mechanism.

The lists of distresses commonly observed in various types of bridges on the basis of materials are enumerated as below:

5.1.1 Concrete Bridges

- **Deterioration/aging:** Deterioration is any adverse change of the normal mechanical, physical and chemical properties, either on the surface or on the whole body of concrete, generally through separation of its components
- **Disintegration:** Disintegration into small fragments or particles due to any cause, collision by vehicle or impact

- **Honeycombing:** Condition of irregular voids caused by failure of the mortar to effectively fill the space between coarse aggregate particles. This may be due to congested reinforcement, insufficient cement content, improper fine/ coarse aggregate ratio or inadequate placement technique.



- **Delamination:** It occurs over large area of corroding reinforcing steel and results in a plane separation within the concrete immediately over the plane of reinforcing steel.

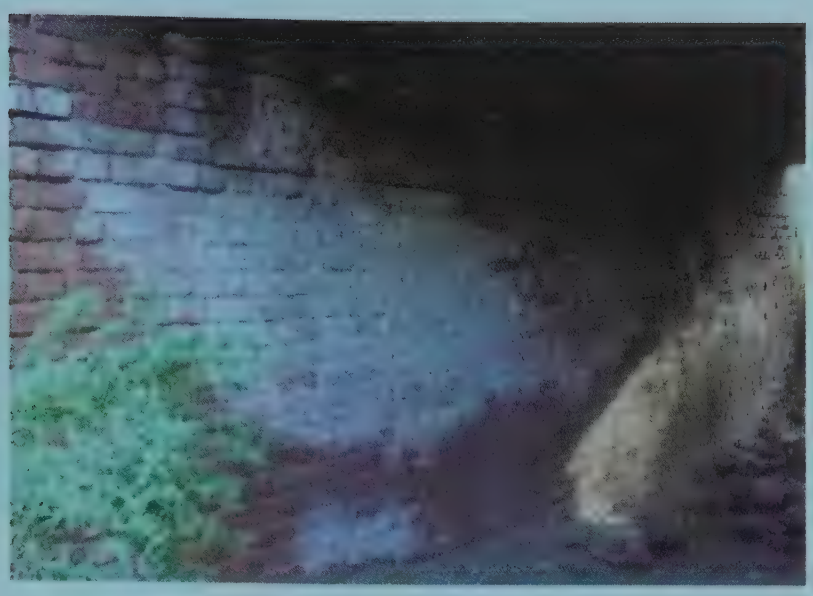
- **Scaling:** is the loss of surface- mortar in concrete. This procedure exposes the aggregate particles and, in its advanced stages, results in the loss of aggregate and loss of section. Scaling is often indicative of inadequate air entrainment.

- **Joint Spalls:** An elongated depression along an expansion, contraction, or construction joint
- **Spalling:** Spalling is a depression, resulting from the dislodgement surface of concrete. Spalling is local disintegration of a portion of concrete surface. The predominant cause of spalling is the corrosion of reinforcing steel in concrete.

- **Leaching:** Water seeping through concrete, dissolves water-soluble components (such as calcium hydroxide) in the concrete, which appear on the underside of the deck, as stains or efflorescence

- **Cracking:** A crack is an incomplete separation of concrete into one or more parts to a variable depth, but visible at surface. Crack can be identified with their length, width, type and location of crack. They may be: Longitudinal cracking, Transverse cracking/ Vertical cracking Diagonal cracking Bending cracking on the corner and Map cracking.

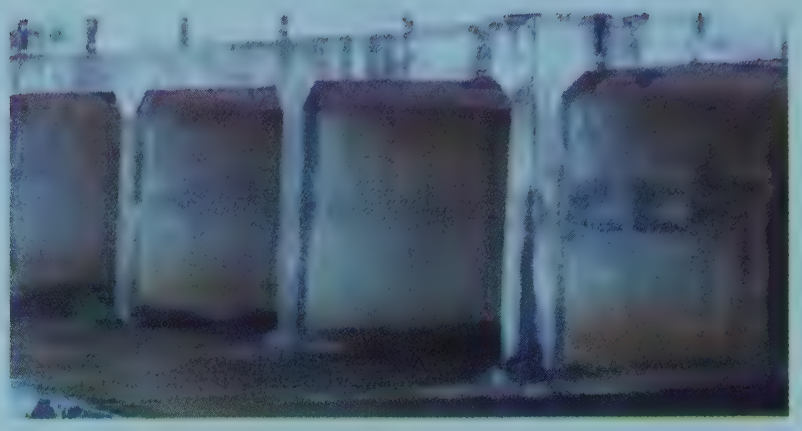
- **Pop Outs (Plain Cement Concrete):** Conical fragments that break out from the surface of the concrete leaving voids which may vary in size from 25 mm to as much as 300 mm in diameter at concrete surface.
- **Pitting (Plain Cement Concrete):** Loss of thin coats of surface mortar directly over coarse aggregate particles, without apparent damage to the aggregate particles. The pits are usually not over 3 mm in depth.
- **Mud Balls:** Small holes in the surface of concrete left by dissolution of mud balls that get mixed with the concrete will dissolve with time and leave holes in the concrete, either by deterioration or by adherence to forms.
- **Discolouration:** Departure of colour from that which is normal or desired.
- **Efflorescence:** A white (salt) deposit on concrete (or brick) caused by precipitation of dissolved salts brought to the surface by the capillary action (leaching) of moisture.



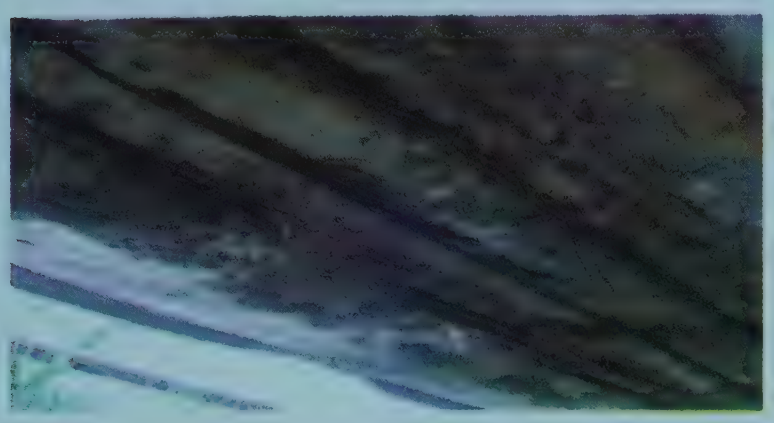
- **Exudation (stalactites):** A liquidity or viscous gel-like material discharged through a crack or opening in the concrete by the leaching water.
- **Encrustation:** A crust or coating, generally hard, formed on the surface of concrete over a period of time by precipitation of minerals out of leaching water.
- **Corrosion Stain:** Stain is formed due to the corrosion of reinforcement.
- **Wear & Tear:** Wear of concrete surface can be due to moving vehicles or due to high hydraulic gradient.
- **Segregation:** Condition in which the coarse and fine aggregate and cement paste, become separated.
- **Excessive Deflection:** This could be due to deficiency in the structural capacity of the superstructure under passage of normal loads. Time dependent stresses also can cause such deflections if the estimated values of shrinkage and creep are different from the actual values.

➢ **Tilting**

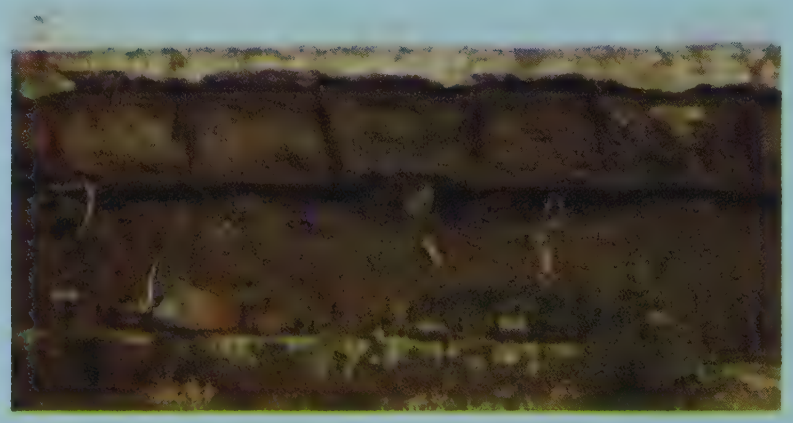
➢ **Staining**



➢ **Corrosion & Exposed Reinforcement**



➢ **Reduction in Area/Section Loss**



➢ **Unevenness/Depressions/Deformation**

➢ **Pot Holes**

➢ **Erosion**

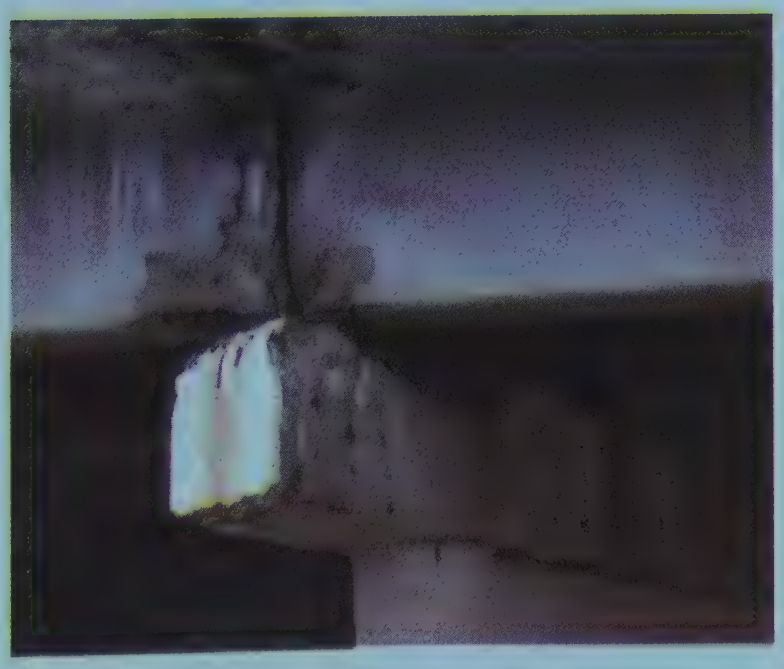
➢ **Excessive Scour**

- **Choking by blocking/damage collection of dust & dirt**

- **Vegetation growth**

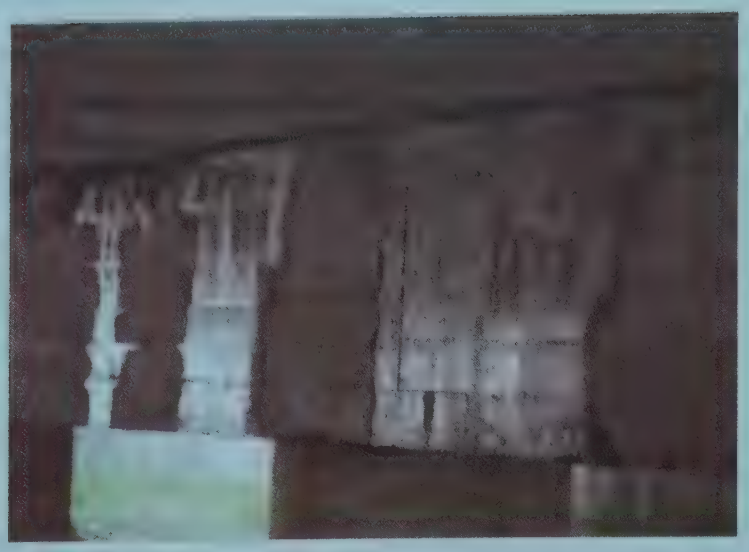
- **Ponding**

- **Aging**



- **Leakage of at joints**

- Dampness



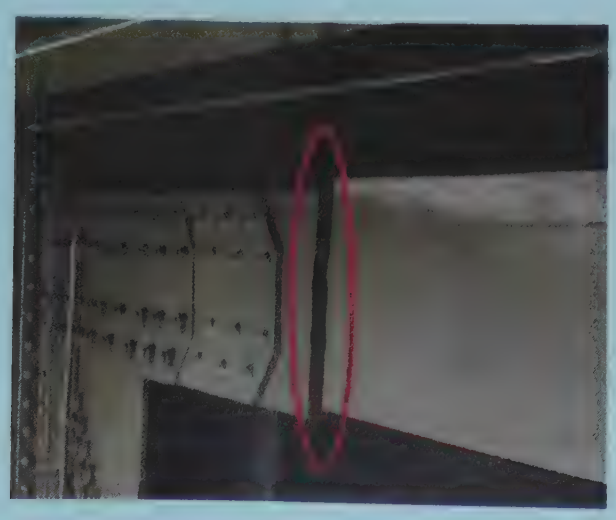
- Settlement or bulging of crates

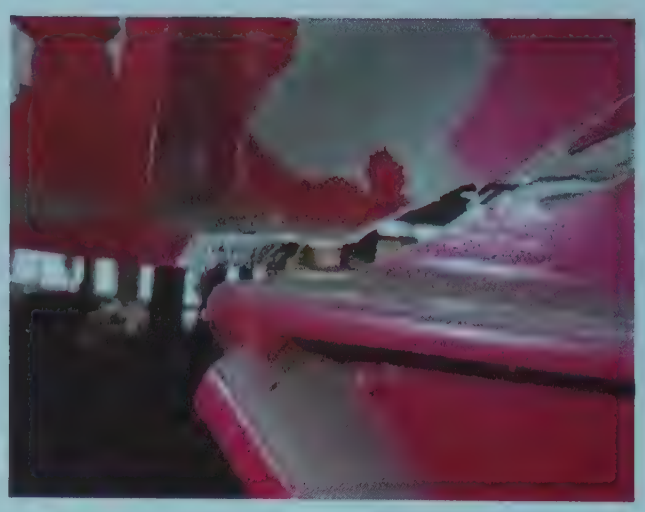
- Damaged or loose kerbs
- Missing elements
- Chemical attack

5.1.2 Steel Bridges

- Corrosion /Rust

- Fatigue Cracking



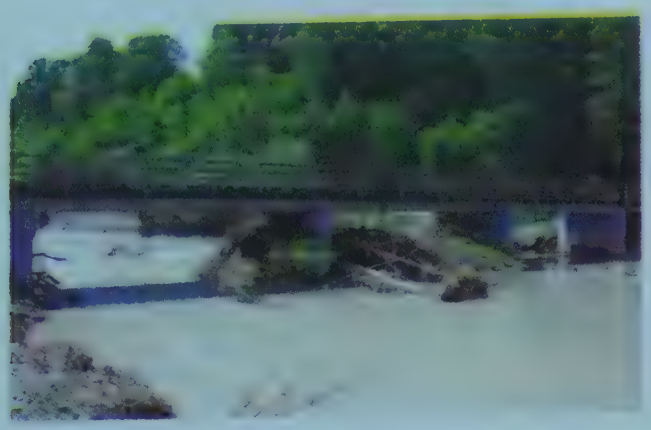


- **Loose bolt or rivet and loose weld near welds and bolt holes**

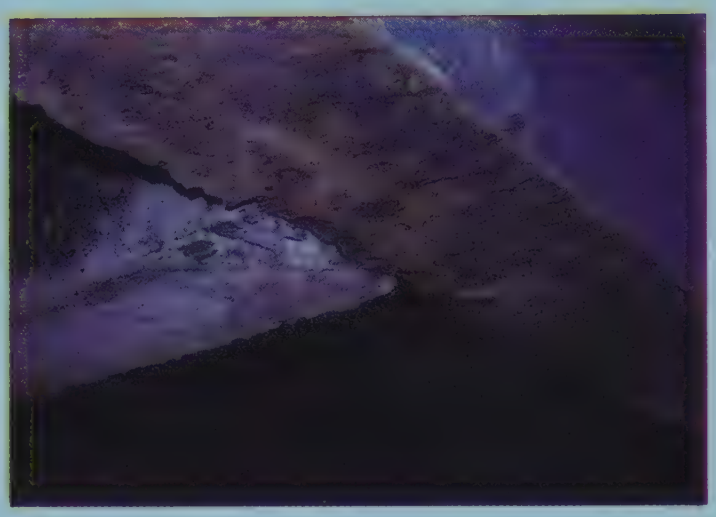
- **Debris on the joints of the steel works/bearing leading to corrosion**

- **Deterioration of paint or galvanizing/ metalizing**

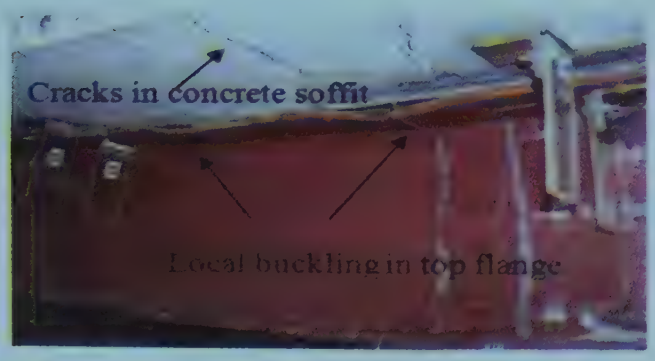
- **Bend in steel members and joints, usually caused by barges or logs/ trees impacting**



- **Loss of section**

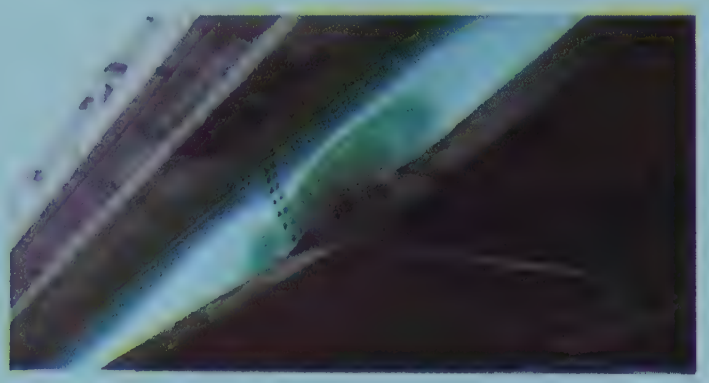


- **Buckling and Bending including misalignment**

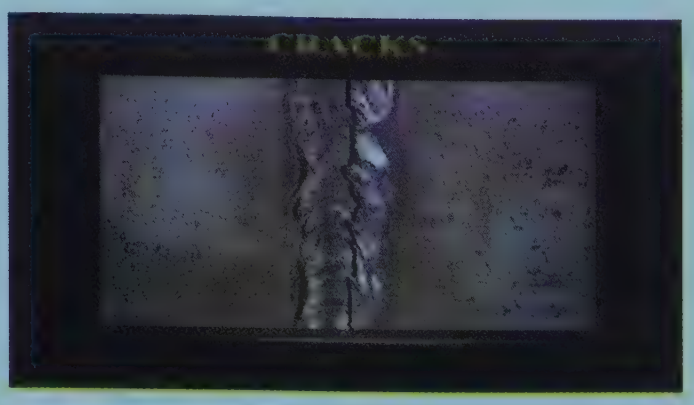


- **Aging**

Damaged connections



- **Weld Cracks**

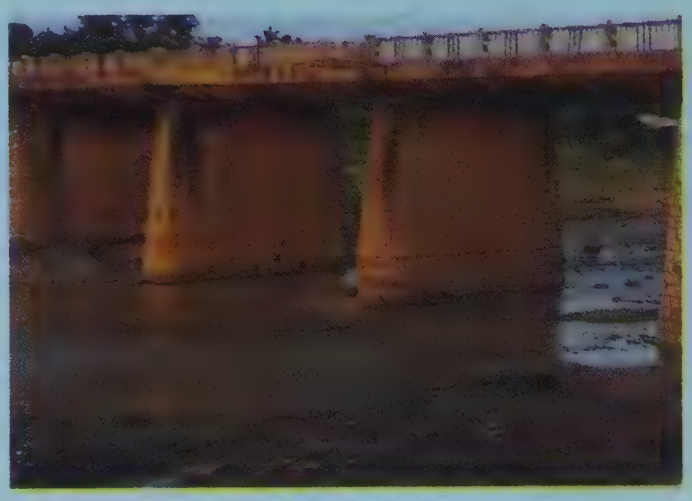


Loss of Welds

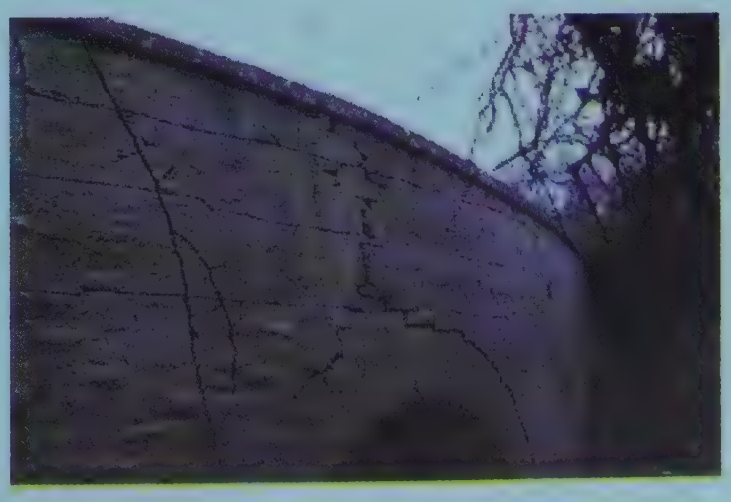
- **Cracking near the bearings**
- **Loose base plates**
- **Unusual Vibration**
- **Excessive deflection**

5.1.3 Masonry Bridges

- **Loosening/Loss of mortar/Poor pointing of joint**



- **Cracks: (vertical cracks due subsidence, Lateral and diagonal cracks indicative of dangerous state, in the vicinity of bearings)**



Scaling

- **Stains**

Bulging

- **Spalling**

- **Carbonation**
- **Delamination**
- **Leaching**
- **Deterioration of Stone/Bricks**

5.1.4 Pre-stressing Steel: In addition to the concrete

- Loss of pre-stress
- Cable Corrosion
- Loose anchorages

5.1.5 Timber

- Cracking and splitting of members due to overload, ageing or under-designing of members.
- Abnormal deflections due to overloads or under designing or imperfect joint
- Infestations decay etc., due to environmental aggressiveness.

- Loosening of joints due to lack of good workmanship

5.2 Commonly Occurred Distresses of Typical Bridge Components

5.2.1 Wearing Surface

It may be affected due to cracks, disintegration, potholes, tell-tale rings etc. As per IRC:SP:83 and IRC:82 may be refereed to for rigid and flexible pavements respectively.

5.2.2. Substructure

- Scour

- Damage near the base
- Movement of piers (Tilting and or shifting)
- Damage due to impact from boats, vessels, floating blocks or trees or vehicles passing under the bridge
- Debris resting against piers
- Vegetation growth on the piers
- Leakage of water from the expansion joints damaging the piers
- Dampness on the piers
- Leaching on the piers
- Silting

5.2.3 Foundation

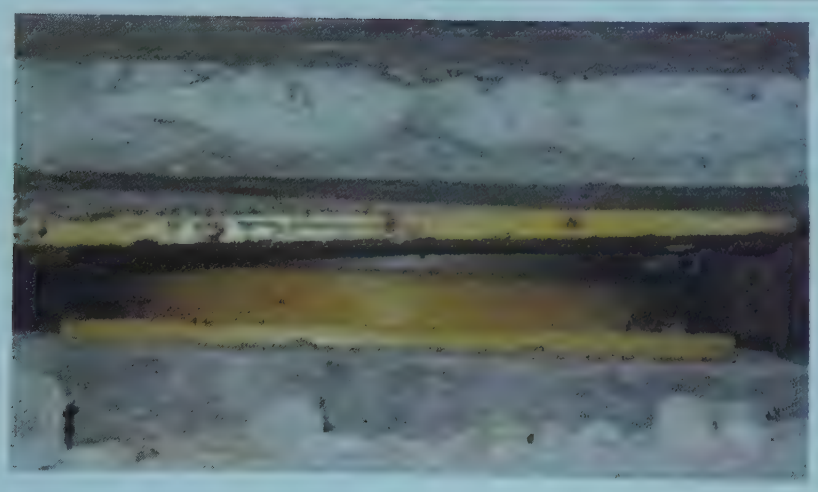
- Settlement
- Abnormal scour
- Tilting
- Cracking
- Disintegration
- Decay of foundation
- Erosion
- Cavitations/honeycombing
- Damage due to impact of floating bodies, boulders etc.
- Seepage damaging the foundation
- Vehicle impact damaging the foundation
- Damaged or loose earthquake restraints

5.2.4 Bearings and Seismic Stoppers

Distresses may vary in accordance with material. Common distresses are:

- **Improper functioning**

- **Tilting**



- **Movements restricted or excess**

- **Corrosion or Rusting of steel parts**

- **Splitting**

- **Deterioration of bed block**

- Jumping off guides
- Missing rollers
- Non-effectiveness of anchor bolts
- Deterioration of materials by process of ageing
- Level of oil
- Abnormal flattening
- Bulging
- Displacement of pads
- Misaligned deck joint
- Shearing of hold down bolts
- Shaking of bed block
- Elastomeric Bearings
- Improper Seating of Hearings
- Bearing deflected permanently
- Separation between Rubber and Steel
- Debris around the Bearing Seat
- Colour change of Elastomeric Pads

- Flattening of Elastomeric Pads
- Buldging of Elastomeric Pads
- Splitting of Elastomeric Pads
- Check the hardness of Elastomer

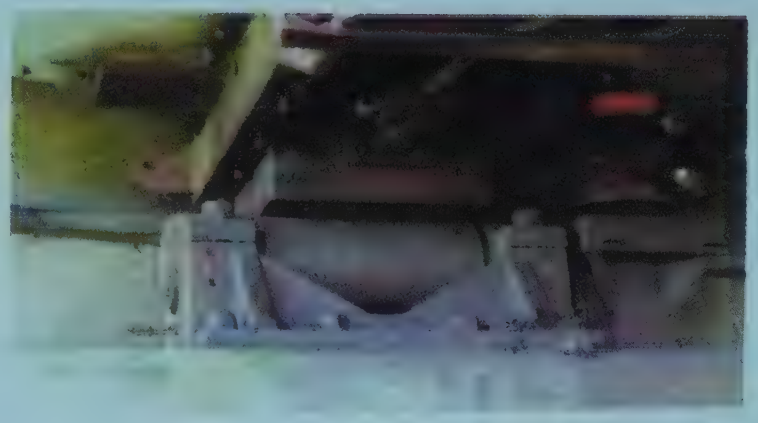
Reasons:

- Bearings not properly set during original construction
- Bottom of beams and substructure seat are not parallel
- Unequal bearing support
- Premature aging of elastomer

Steel Bearings: Same as steel

- **Vertical/Tilting**

- **Corrosion**



- **Loose**

Reasons:

- Abutment moving inward due to pavement pressure or foundation settlement
- Unequal bearing pressure of all bearings
- Collision damage of pier
- Leaking expansion joints
- Debris on abutment seat

Bearing Seat:

- Debris
- Leaching
- Scaling
- Honeycombing
- Delamination
- Spalling
- Cracking
- Bolt missing

5.2.5 Protective Works

Protective works include guide bund, protection around abutments and spurs etc.

- Damage to the layout
- Damage to the cross section profile
- Damage to slope
- Erosion of toe walls
- Damage to flexible apron
- Damage to curtain walls
- Abnormal scour
- Thickness of pitching in the slopes
- Width of apron
- Thickness of apron
- Condition of floor protection works
- Condition of impervious floor
- Quality of reserve stone material

5.2.6 Utilities

- Check whether the utility is authorized
- Leakage to water and sewage pipes
- Damage to leakage utilities
- Damage caused to telephones or electric cables
- Proper lighting facilities
- Damage due to other utilities

5.2.7 Drainage Spouts & Vent Holes

- Clogging
- Deterioration
- Damage
- Projection of the spouts on the underside
- Badly built road drainage near bridge
- Blocked or damaged road drain
- Water on the deck
- Blocked or damaged deck drain
- Check whether structural members are being affected
- Check for adequacy of drainage spout
- Subway drainage
- Subway pumping arrangement
- Submersible bridges functioning

5.2.8 Aesthetics

- Visual intrusion
- Hoarding
- Vegetation growth

The details of maintenance and repairs done shall be collected and noted whether all the actions for maintenance and repairs recommended during last inspection have been carried out.

5.2.9 Waterway

- Debris against piers or abutments
- Remain of an old bridge D/S or U/S of the bridge
- Fencing or building under bridge
- Island formation
- Tree or bush growing under bridge
- Abnormal change in flow pattern
- Damage to walls
- Loss of pitching

- Sign of abnormal afflux from U/S and D/S watermarks on piers
- Erosion of bank
- Check the maximum flood level observed during the last year and mark the same on the pier/ abutment both on U/S and D/S
- Check adequacy of waterway

5.2.10 Expansion Joints

Expansion joints allow the bridge to expand and contract with temperature changes and to allow for rotation of the beam-ends as the beams deflect under traffic loading. It is imperative that these joints be maintained with the proper opening to allow the bridge to function as it was designed. Common distresses are:

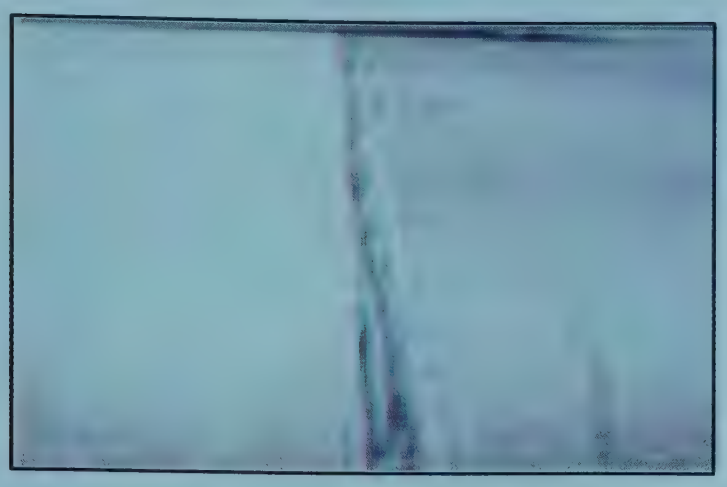
- No smooth riding quality
- Rattling
- Projecting parts visible
- Secureness and alignment disorder
- Components are not in order
- Leaking joints
- Disturbed sealing
- Debris accumulation
- Loss of proper anchorage
- Loss of aesthetics gap
- Jamming by dust
- Vegetation growth
- Damage to concrete at deck end or dirt wall near expansion joint
- Steel portion corroded
- Crack / damage in wearing course near expansion joint
- Vibration of joint
- Joint rutting/ shoving
- Hole in the Glared Exposure of reinforcement at the edge of joint
- Water tightness of the joints

Strip-Seal/ Compression Seal Expansion Joints

- **Strip seal torn or pulled out**

- **Strip seal missing**

- **Hole in the Gland**
- **Loose Seal**

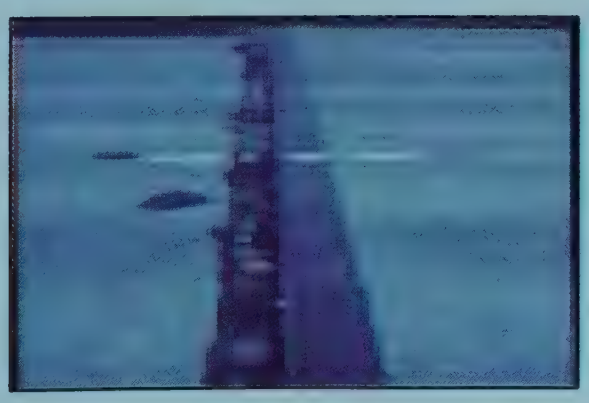


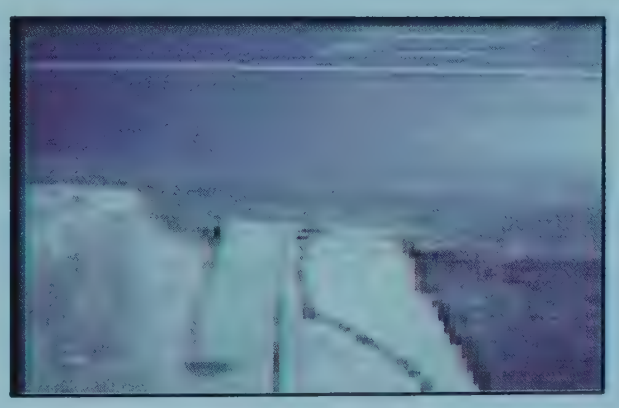
Joint leaking

Sliding Plate Expansion Joints:

- **Loose sliding plate/anchorage**
- **Cracked sliding plate**

- **Joint closed due to pavement pressure**





- **Gouged Assembly**

5.2.11 Approach Slab

The approach slab provides a transition between roadway pavement and the bridge. The approach slab acts as an intermediate bridge to span the portion of embankment directly behind the abutment/backwall, which was excavated to construct the abutment/back wall. This

area is difficult to compact after construction of the abutment/back wall and is prone to settlement. The approach slab bridges the gap between the rigid abutment and the undisturbed embankment beyond the area excavated. On completely new roadways (new alignments), there may not be an area of embankment beyond the area of embankment that will not settle somewhat even with optimum compaction; thus the pavement end of the approach slab may still settle, creating an uneven transition onto the bridge. Settled approach slabs, if left uncorrected, cause undue impact upon the bridge, especially from trucks. It is therefore important to keep the approaches to the bridge as smooth as possible.

5.3 Probable Causes of Distresses

Deterioration is any adverse change of the normal mechanical, physical and chemical properties, either on the surface or on the whole body of concrete, generally through separation of its components.

The deterioration of concrete bridges takes place mainly because of four types of action i.e., chemical, physical, mechanical and electrochemical. The details of the various elements acting on the bridge and corresponding deterioration along with the remedial measures are given in SP:40.

Usually, a bridge deteriorates from the deck downwards. The deck is the first element of a bridge that is impacted by the traffic. It is also exposed to worst environment and temperature variations.

5.3.1 Bridge Failure Factors and their Brief Description

Summary of the factors causing bridge failure are given below:

Idea is to just give the details of various distress types and not to educate about the processes of deterioration.

Inadequate Structural Design: It includes deficiency in design on account of errors, oversight, omission, or conceptual flaw (s) that could have occurred during the design process. It also includes inadequacy in the codal provisions and the related standards.

Inadequate Hydraulic Design: It implies deficiency in hydraulic design on account of errors, oversight, omission, or conceptual flaw(s) that could have occurred in designing waterways and span arrangement.

Inadequate Functional Design: It implies the insufficiency of bridge width, approach alignment, clearances and drainage.

Poor Quality Material: It includes improper selection, stacking and utilization of materials and deviations from the specifications.

Poor Quality Construction: It includes construction deficiencies, such as poor workmanship, improper construction methods and procedures, adoption of poor quality control measures and errors in supervision (e.g., misalignment of anchor bolts, improper installation

and inadequate temporary structure to support the bridge components, insufficient concrete cover, etc.).

Poor Subsoil Conditions: It implies poor quality of foundation and subsoil strata. Poor subsoil conditions may result in uneven settlement of the foundations, cracking, poor drainage, underestimation of the capacity of soil and its properties and abutment erosion and endanger the safety and stability of a bridge.

Abnormal Floods: In spite of all the efforts and the use of latest models to predict the design discharge, the risks to a bridge due to abnormal flood persist. It can result in scouring, horizontal movement of the foundation, uneven settlement of the foundation, impact of debris, migration and/or inadequacy of waterways, mining and dredging of sand and gravel.

Earthquakes: Earthquake may result in the relative displacement of members leading to cracking and even collapse of a bridge.

Environment: It includes climatic variations, strong winds, temperature extremes, alternate wetting and drying, use of deicing chemicals and salt, fire, freeze-thaw moisture and proximity to industrial areas. Poor drainage

Aging: It refers to normal degradation, wear and tear due to aging and poor quality inspection, improper maintenance practices and lack of resources.

Corrosion: It refers to the loss of cross-sectional area of reinforcement due to carbonation, corrosive attack of chemicals and chlorides, deicing agents and animal wastes.

Cracking: It refers to the loss of bond and section, due to creep, shrinkage, fatigue, fire, non-functioning of bearing, temperature gradient, chlorination and carbonation. It may also be caused by plastic settlement, plastic shrinkage, early thermal contraction, long-term drying shrinkage, crazing, corrosion of reinforcement and alkali-aggregate reaction.

Traffic Volume: It refers to changes in traffic volume and overstress due to heavy traffic load. Accident damage (heavy items falling from a vehicle)

Combination of Loads: it refers to designer's inability to take into consideration the most appropriate and correct combination of loads to be carried by the bridge.

5.3.2 Types of Cracks and Their Causes

Cracks can occur in concrete during any of the three phases of its life namely,

i) Plastic phase,

ii) During hardening phase and

iii) After hardening phase.

The cracks may be classified as below:

Structural Cracks

Various causes of structural cracks are given below:

- Differential settlement of staging supports
- Differential settlement of supports
- Overload
- Deficient design
- Bad construction
- Inadequate detailing
- Differential settlement of foundations

Non-structural Cracks

Various causes of non-structural cracks are given below:

- Plastic shrinkage
- Plastic settlement
- Constraint to early thermal movement
- Constraint to early drying shrinkage
- Sulphate attack on cement in concrete
- Long term drying – shrinkage cracks
- Corrosion of reinforcement due to
  - Chloride attack on reinforcement
  - Carbonation effect on concrete
  - Simple oxidation of reinforcement due to exposure of moisture
- Alkali- aggregate reaction
- Fabrication, shipment and handling cracks in precast, prestressed or reinforced concrete members
- Crazing
- Weathering cracks

The various types of cracks and their position is given in **Fig. 5.1.**

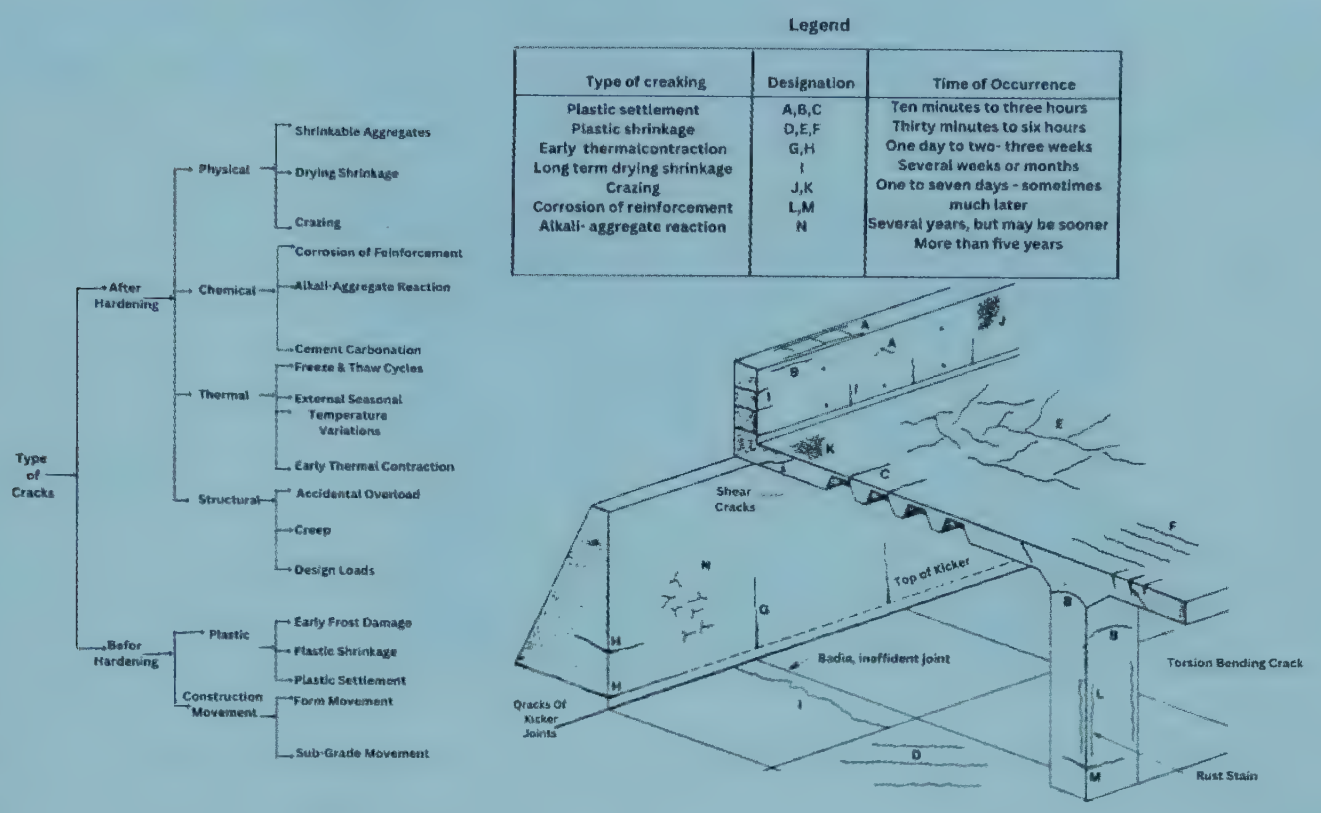


Fig. 5.1 Types of Cracks

5.4 Method of Evaluation of Distresses

For detailed procedure for distress evaluation procedure IRC:SP:40 may please be referred to

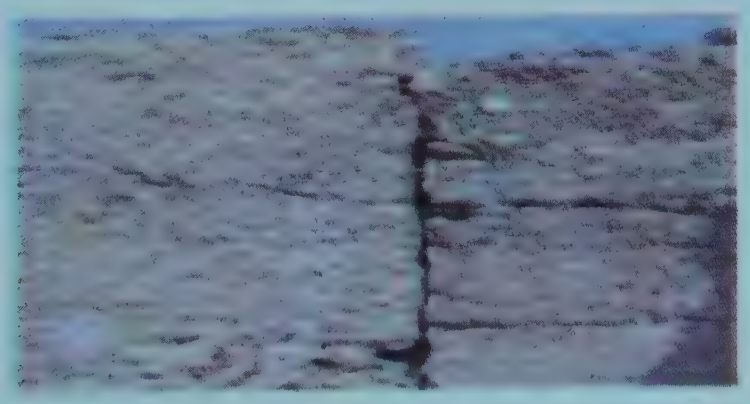
5.4.1 Mechanical Element

5.4.1.1 Impact

Damage caused by impact due to another body. For instance if a bridge vertical clearance is less than the height of the vehicle crossing the movement will create impact. Causes may be: Accidents, Over Dimensional & Over Weighted Consignments

5.4.1.2 Abrasion

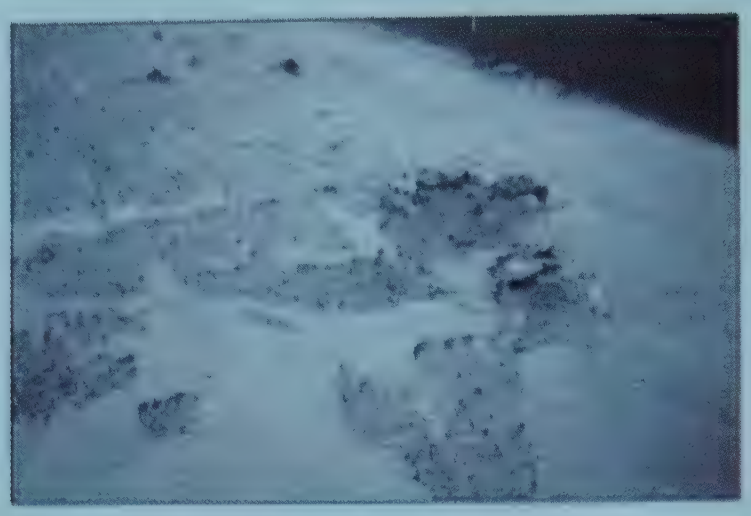
Abrasion damage occurs when the surface of concrete is unable to resist wear caused by rubbing and friction of another harder body. Causes may be: wind-borne particles can cause abrasion of concrete, vehicular traffic



Abrasion

5.4.1.3 Erosion

Erosion is a particular form of wear due to wind, water which is removal of Material from the surface. It depends on the speed, hard dust particles contents and concrete quality. Causes may be: High Wind, Water

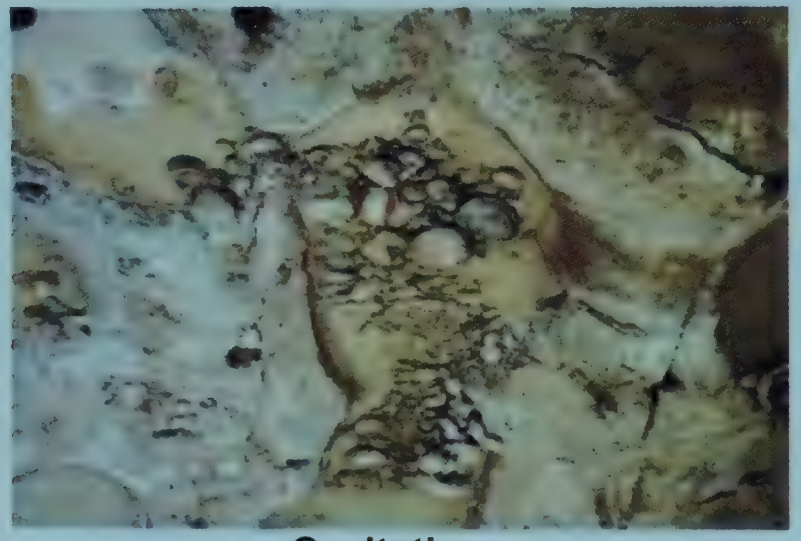


Erosion

5.4.1.4 Cavitation

Cavitation is the formation of bubbles or cavities in a liquid.

Causes: discontinuity or irregularities in the path of high velocity water flow.



Cavitation

5.4.1.5 Overloading

Properly designed and constructed concrete members are usually strong enough to support the loads for which they are designed, but if the live load passing over the bridge are more than what the bridge is designed for the chances of bridge getting deformed due to overloading are more. Causes may be: Over Dimensional & Over Weighted Consignments.

Failure due to Overloading

5.4.1.6 Fatigue

Fatigue is a phenomenon where a material loses its original strength due to cyclic loading with successive damage development. Fatigue in concrete depends on the load amplitude and the number of cycles as well as on the stress level.

Causes: Exposed to repeated loading, the traffic volume is increasing, the axel loads are larger and the traffic speed limits are higher.

Fatigue Failure

5.4.2 Physical Element

5.4.2.1 Temperature

Concrete changes slightly in volume called Contraction and Expansion. It occurs with variations of temperature and when the contraction or expansion is restrained, damage can result.

5.4.2.2 Thermal Changes

Concrete expands when heated and contracts when cooled. Thermal expansion and contraction of concrete varies with factors such as aggregate type, cement content, water-cement ratio, temperature range, concrete age and relative humidity.

a) Temperature variations can occur either as a result of externally applied heat or cold or due to the quite considerable quantities of heat generated by concrete during setting

and hardening. In a large volume of fresh concrete, the heat generated is not easily dissipated or a substantial rise in temperature can result. If precautions are not taken to limit the difference in temperature between the interior and the surface of the concrete.

b) In other situations with smaller volumes, the heat generated during setting and initial hardening raises the temperature of the concrete and when the hardened concrete subsequently cools and attempts to contract, cracking may occur if restraint is present.

c) Heat from external sources produces thermal expansion and if this is restrained, large local compressive stresses can be set up and result in spalling.

Symptoms: - The temperature differential can Result in cracking.

The Common examples of such cracking are: the parallel, regularly spaced cracks which often occur when concrete is cast against older concrete which has already hardened, the cracks which occur in walls or panels bridging between fixed parts of a structure.

Thermal contraction and expansion sometimes cause pre-existing cracks to open and close with variation in ambient temperature.

Cracks due to thermal contraction

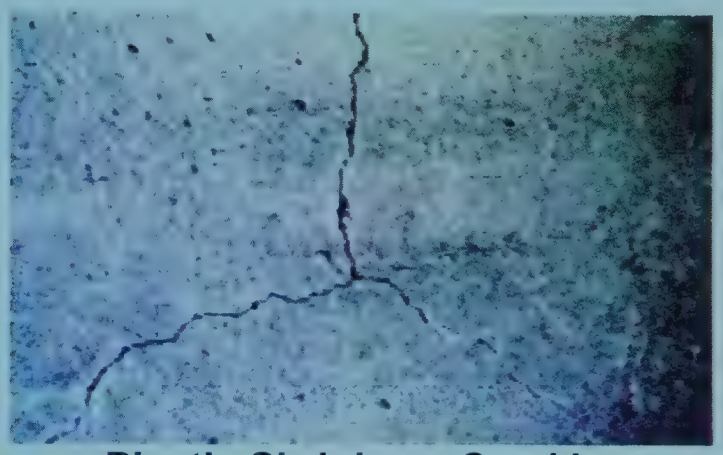
5.4.3 Shrinkage Induced Distress

Concrete changes slightly in volume called shrinkage. Fluctuations in moisture content and temperature in concrete causes shrinkage.

5.4.3.1 Plastic Shrinkage Cracking

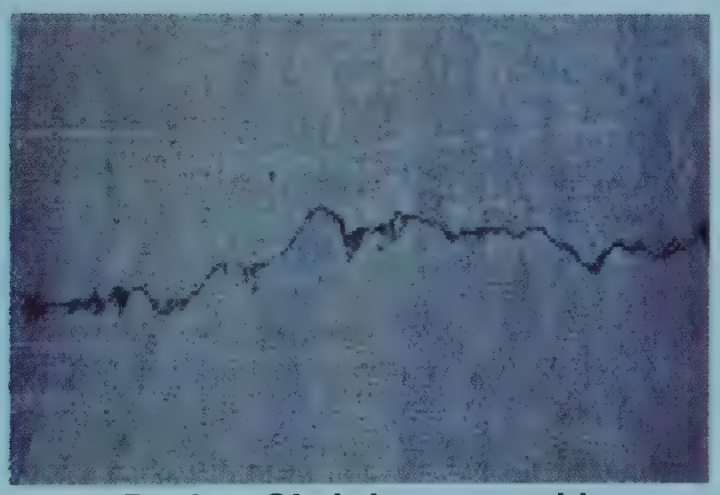
Plastic shrinkage cracks can occur when water evaporates from the surface faster than it is replaced by bleed water. The drying of the surface concrete develops tensile stresses which can ultimately lead to cracking. Drying Shrinkage cracking: Cracks formed by restraint to volume changes caused by loss of excess water. Drying shrinkage cracks depends on the rate of drying and take years after casting. Concrete near to corners and edges is particularly prone to cracking as loss of moisture takes place from the adjacent surfaces.

Shallow cracks of varying depth these cracks are often fairly wide at the surface.



Plastic Shrinkage Cracking

The cracks are usually approx. at right angles to the direction of restraint.



Drying Shrinkage cracking

5.4.4 Chemical Elements

5.4.4.1 Chemical attack

It occurs when aggressive liquids of damp chemicals come in contact with concrete. Chemical attacks on concrete structures causes deterioration of structure and its durability is affected. The life of structure reduces and it can lead to failure of structures.

Causes : Chemical attack on concrete happens due to presence of aggressive chemicals in solutions. The type of aggressive chemicals that causes chemical attack is mentioned as below:

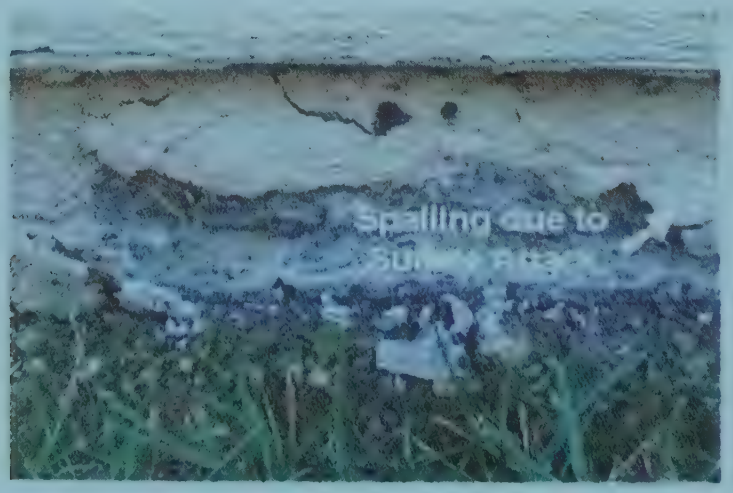
5.4.4.2 Chlorides Attacks on Concrete Structures

High concentrations of chloride ions cause corrosion of reinforcement and the products of corrosion can disrupt the concrete. Chlorides can be introduced into the concrete either during or after construction from cement, water and aggregate and sometimes from admixtures.

Chlorides attacks on concrete structures

5.4.4.3 Sulphates Attack on Concrete Structures

Sulphates are present in most cement and some aggregates. Sulphates may also be present in soils, groundwater and sea water, industrial wastes and acid rain. The products of sulphate attack on concrete occupy a larger space than the original material and this causes the concrete to disintegrate and permits corrosion of steel to begin.



Sulphates attacks on concrete structures

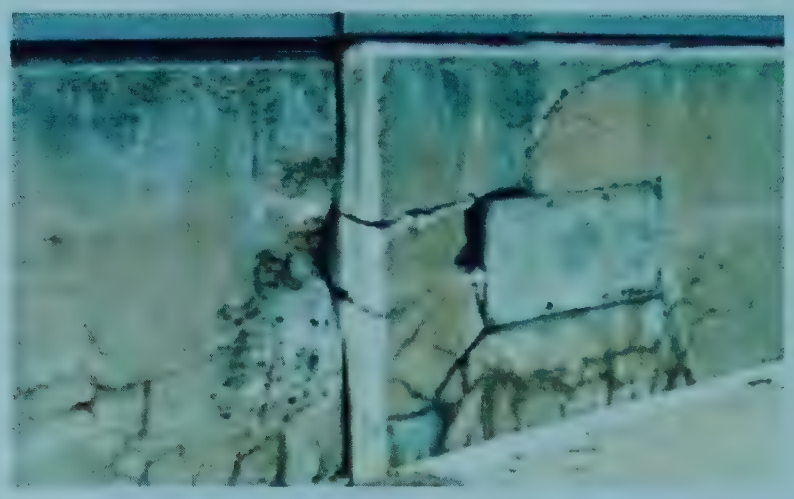
5.4.4.4 Carbonation of Concrete Structures

Carbonation is the process by which carbon dioxide from the atmosphere slowly transforms calcium hydroxide into calcium carbonate in concrete. The concrete itself is not harmed and increases in strength, but the reinforcement can be seriously affected by corrosion as a result of this process.

Carbonation of concrete structures

5.4.4.5 Alkali-Silica Reaction in Concrete Structures

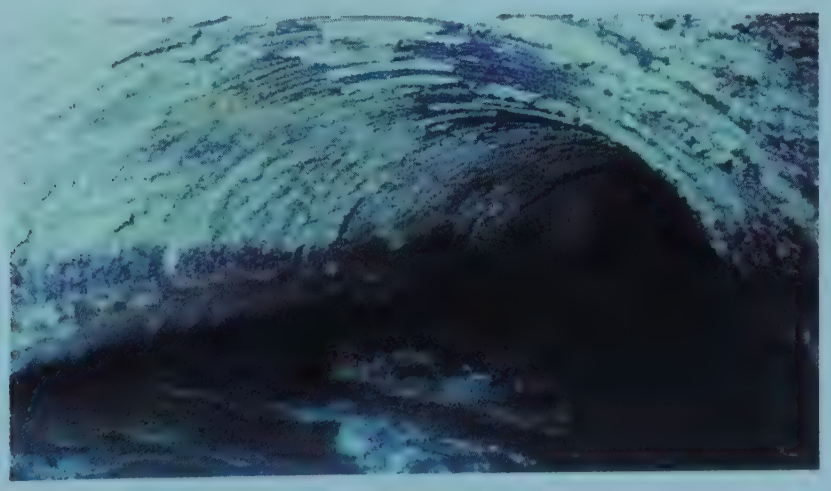
A chemical reaction can take place between alkali in cement and certain forms of silica in aggregate. The reaction produces a gel which absorbs water and expands in volume, resulting in cracking and disintegration of the concrete.



Alkali-Silica reaction in concrete structures

5.4.4.6 Acids Attacks on Concrete Structures

Portland cement is not acid resistant and acid attack may remove part of the set cement. Acids are formed by the dissolution in water of carbon dioxide or sulphur dioxide from the atmosphere. Acids can also come from industrial wastes. Good dense concrete with adequate cover is required and sulphate-resistant cements should be used if necessary.



Acids attacks on concrete structures

Symptoms : Cracking, Map cracking, Spalling

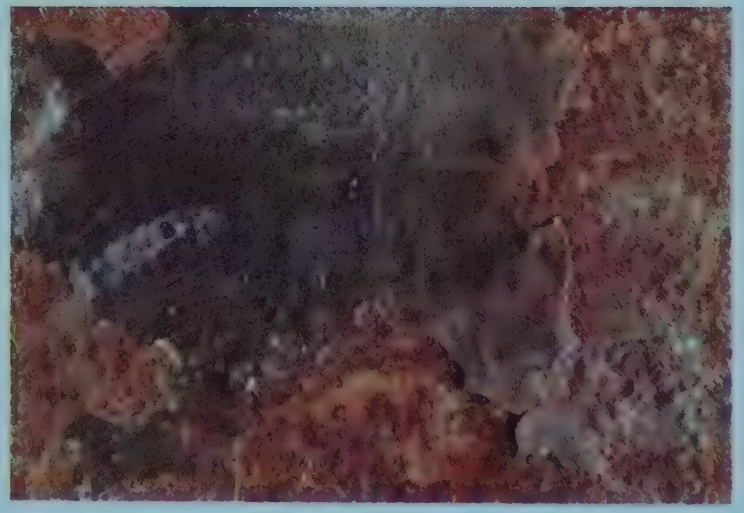
Other than above three elements concrete deteriorates due to structural deficiency in structure which is caused due to:

5.5 Types of Steel Corrosion

The corrosion is by far the most critical distress seen in steel. The various types are shown below:

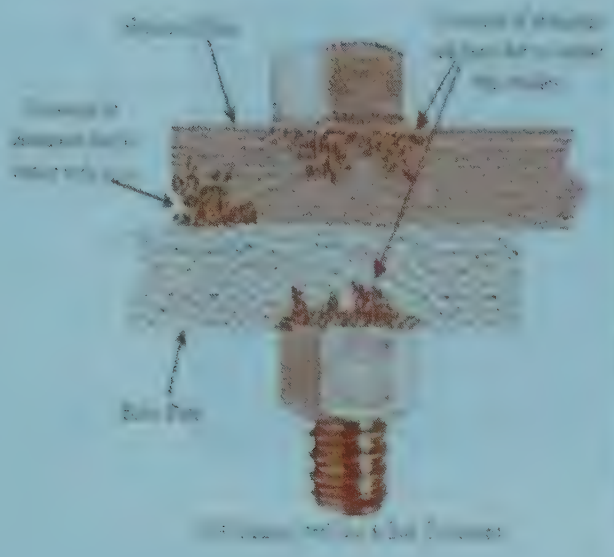
i) **Atmospheric corrosion**

ii) **Uniform Corrosion**

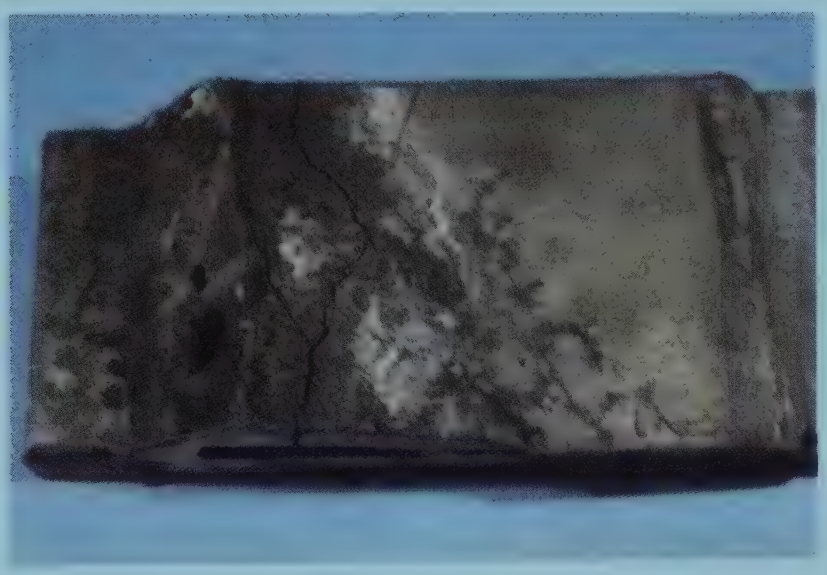


iii) **Pitting Corrosion**

iv) Fretting Corrosion

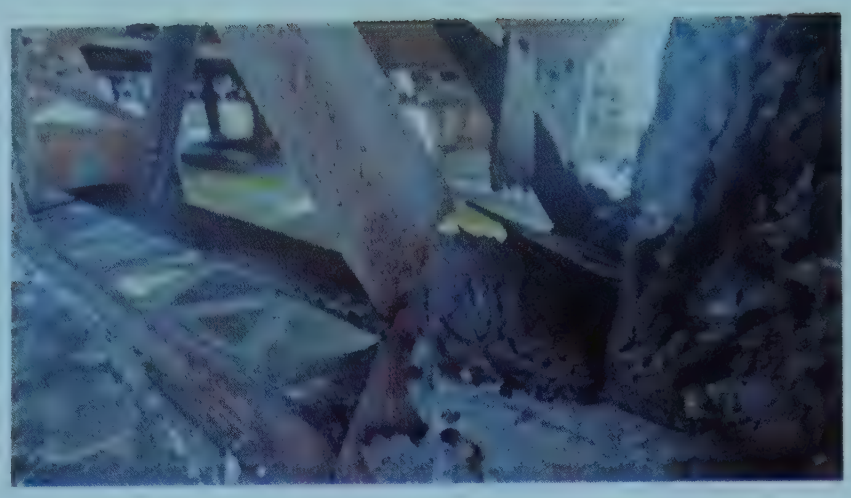


v) Stress Corrosion



vi) Inter-granular Corrosion

vii) **Corrosion Fatigue**



5.6 NDT Methods

The details of various NDT Tests Already in SP:40 for evaluation of concrete bridges. However, commonly NDT methods used are given below:

NDT Tests for detection of cracks/voids/delamination/etc. in concrete bridges

i) Boroscope

ii) Nuclear Method

iii) Spectral Analysis of Surface Waves for Unknown Foundation

NDT Tests of Steel Bridges

i) Liquid Penetrant Inspection /Dye Penetration test

ii) Magnetic Particle Inspection

iii) Eddy Current Testing

iv) Radiographic Testing

v) Ultrasonic Inspection

vi) Complete Structural Testing

vii) Acoustic Emission Techniques

NDT Tests of Masonry Bridges

i) Flat Jack Testing

ii) Impact Echo Testing

iii) Impulse Radar Testing

iv) Infrared Thermography

v) Boroscope

5.7 Description of Condition States

5.7.1 Standard definitions for condition states

Different countries and researchers have adopted different scales of condition states rating for assessing the state of bridge health. In spite of the single objective of representing the overall condition of a bridge based on the visual inspection, there is no unanimity on the number of scales and their description. From the analysis of the scales of rating condition state, it is observed that following three main objectives are to be included in the definition of condition state

5.7.2 Strength of various elements of a bridge

Strength refers to the ability of a bridge element to sustain all the forces that are likely to occur due to its own weight and environment, interdependencies and its usage. It can be achieved by using appropriate materials and providing requisite dimensions. The strength also indicates the soundness of a bridge.

5.7.3 Safety to road users

Safety refers to the passage of users through a bridge without any harm or discomfort. Safety can be ensured by proper alignment, adopting appropriate geometric standards and providing auxiliary means of protection.

5.7.4 Serviceability

Serviceability indicates the ability of a bridge to serve the intended function, or in other words, to satisfy the present requirement of users. Serviceability can be enhanced by providing adequate width, number of lanes and clearances over and/or under the bridge.

Condition states also include the type of distresses causing bridge failure and the urgency of maintenance. Some countries and researchers tried to accommodate one or two types of distresses while defining the scales of rating condition states. Condition states are the relative qualitative measures of the condition of a bridge on the basis of visual inspection. Condition states are described by terms, such as excellent, fair, critical etc. They are designated by numeric/roman numbers ranging from 3 to 10, either in the ascending or descending order of degree of the fitness of a bridge. Majority of countries use five-point scale of rating for condition states. While higher number of condition states are difficult to judge, lesser numbers are inadequate to completely describe all the conditions. reported as condition ratings.

Five condition states have been selected for the preparation of comprehensive definitions. They are: excellent, good, fair, poor and critical. They are denoted by roman numbers. Condition states have been defined taking into consideration the requirement of strength, safety and serviceability of a bridge. In addition, some other factors have also been considered while defining the proposed condition states. These are: extent and severity of each type of distress, urgency of maintenance, type of maintenance. The description for the condition states are given in **Table 5.1**

Table 5.1: Descriptions of Condition States

Condition State	Description
I (Excellent)	Sound structural condition; component do not individually or as a whole impair the strength, stability, traffic safety, durability and serviceability of the structure; only constructional deficiencies may be present. Extent of deficiencies is nil or insignificant; Severity of deficiencies is very low; No need of repair except routine maintenance. Functionality of the bridge is more than adequate.
II (Good)	More than satisfactory structural condition; component do not individually or as a whole impair strength/stability; traffic safety, durability and/or serviceability of the structure might be impaired slightly in the long term. Extent of deficiencies is minor; Severity of deficiencies is low; No urgent action needed except low cost regular maintenance works; specialized maintenance and repairs may be needed at convenience. Functionality of the bridge is adequate.
III (Fair)	Satisfactory structural condition; strength, stability and traffic safety of the components/structure is assured however considerable reduction is possible in the long term; serviceability and durability of the affected component is reduced and durability of the structure might be impaired considerably in the long term. Extent of deficiencies is major; Severity of deficiencies is medium; Specialized maintenance and repairs needed soon; some damages need monitoring. Functionality of the bridge is just adequate.
IV (Poor)	Structurally deficient bridge; strength/stability/traffic safety no longer assured; durability may be affected in short term; monitoring is required; restriction of use of the bridge may be needed. Extent of deficiencies is large; Severity of deficiencies is high; Rehabilitation/replacement on programme basis is needed; measures for reconstruction or warning signs for upholding traffic safety might be necessary in the short-term; detailed investigations and economic analysis is required for justification of funds. Functionality of the bridge is less than adequate.

V **(Critical)**	Weak structural condition; partial failure or risk of total failure of the component or as a whole; durability of the structure is no longer ensured; immediate propping of the structure and closing may be required Extent of deficiencies is very large/expensive; Severity of deficiencies is very high; Repair/rehabilitation/ replacement is required immediately; design strength, expected serviceability and desired remaining service life of a component/bridge can no more be achieved with economic costs. Functionality of the bridge is inadequate.

Note: All the distresses observed during either visual inspection or investigated by NDT methods are hence forth to be categorise in to five condition states on the basis of measurement and or testing at the bridge site. A particular member may be affected by more than one distress types depending up on the type of the material. Measurement of dimensions of members should be explicitly mentioned in the document if drawings are not available. In order to get the consistent inspection results distress types may be correlated to condition states. The details are given in **Chapter 7**.

Various distress types in accordance with materials as well as bridge components have been presented. There may be number of distresses for which description and photographs are not given. For Example: For Pre-stressing Cables, Cables of Suspension Bridges, Extra dosed Bridges, Cable Stayed Bridges, Bearings, Expansion Joints, Paintings, Signage, etc.

CHAPTER 6
INSPECTION OF BRIDGES

6.1. Types of Inspection

Depending on the objective of inspection, the type of inspection and its frequency varies. The inspection may be daily patrol, preliminary inspection; inspection before opening to the traffic, inspection at the end of Defect Liability Period (DLP), during the service life inspection may be routine inspection, general inspection, major inspection, special inspection, underwater inspection and exceptional inspection. It is suggested that inspections may be categorized in to four categories namely, Routine, Principal/Detailed, Emergent/ Special (due to natural and manmade calamities) and Underwater Inspection as mentioned below:

6.1.1 Routine Inspection

Routine inspection shall be carried out periodically by engineering officers of the authority in charge of bridges. The purpose is to report the fairly obvious deficiencies which might lead to traffic accidents or lead to high maintenance and repairs cost, if not attended in time. The routine inspection will have to rely mainly on visual assessment using conventional standard tools and methods.

6.1.2 Principal/Detailed Inspection

This is more intensive and detailed inspection and will involve close examination of all elements/components of the structure. It may be carried out before opening to the traffic, at the end of DLP and thereafter at regular intervals. It will be primarily visual observation supplemented by assessment of various distresses including Non destructive Testing for assessment of distresses wherever appropriate & necessary.

6.1.3 Emergent/Special Inspection

This shall be undertaken in the event of unusual occurrences such as strong earthquake, floods, winds, accidents, passage of unusual loads, major weaknesses noticed during routine or principal inspection, unusual settlement of foundations and substantial changes in the traffic pattern. In case of any bridges of similar design and constructed almost at the same time are showing some distresses, all such bridges may be undertaken with special inspections. Such inspections may require a good deal of supplementary testing and structural analysis and will invariably require detailed involvement of design wings/organization and expert knowledge in the relevant fields who should be senior level engineers.

6.1.4 Underwater Inspection

It is similar to Principal Inspection. Underwater inspection shall be carried out during Principal Inspection of all the bridge components which remains under submergence or during the severe floods to ascertain the scour depth. This shall be carried out in addition to the detailed visual inspection with the help of requisite cameras/binoculars and NDT tests suggested by the bridge expert. If so needed underwater routine visual inspection ("Swim-by" inspection) may

also be carried out at the frequency of routine inspection. The bridge inspectors performing the underwater inspections must be qualified both as an inspector and a diver. Diving is an inherently dangerous activity that requires significant training, specialized equipment and experience operating in the hostile underwater environments often found at bridges. Whichever may be the underwater inspection all the findings that is location, extent and severity of all the distresses encounter in to classification that Condition States enumerated in **Chapter 5** that is Excellent, Good, Fair, Poor and Critical.

6.2 Time and Frequency of Inspection

Each officer responsible for inspection shall prepare a calendar of inspection of bridges under his/her jurisdiction. It is desirable to undertake inspection in such periods of the year which are most critical for evaluation of the performance of the structure, e.g. items such as foundations, protective works, scour effects, maximum flood levels etc. during and after the monsoons, structures affected by strong winds during those seasons when winds are prevalent, bearings and joints during temperature extremes when there is a likelihood of maximum movement, etc. All major and special type bridges like pre-stressed concrete continuous structures, suspension bridges, cable stayed, girder bridges, etc. should also be inspected periodically. To assess whether repairs have been carried out efficiently or not, inspections should generally be undertaken during the post monsoon season.

6.2.1 Routine Inspection

This shall be at least once a year, but preferably twice a year i.e. before and after monsoon. However, bridges located in hilly terrain prone to effects of landslides and bridges subjected to severe exposure conditions shall be invariably inspected twice a year i.e. before and after the monsoon.

6.2.2 Principal inspection

First shall be done before the bridge is open to the traffic and the second before the Defect Liability Period (DLP) of contract expires but not later than six months after completion and opening of the bridge to traffic. Thereafter, Principal Inspection shall be followed by subsequent inspections at three years intervals. The observations made in the first principal inspection shall serve as a bench mark for subsequent inspections. More frequent principal inspections shall be essential if the routine inspection reveals any distress in the components of bridge structure.

6.2.3 Underwater Inspection

This shall be carried out at five years interval. However, the same may be carried out along with every alternate principal inspection that is in six years interval.

6.3 Bridge Inspector: Qualification and Experience

While, the Inspections shall be taken by the experts in the Government /Public sector organisations the bridge inspections alternately, may be carried out by engaging agencies having the similar experience & qualifications.

All bridges shall be inspected by a qualified and experience engineer. Inspector shall be at least Diploma with minimum 10 years of experience and Graduated in Civil Engineering with five years of experience. Bridge inspectors should have undergone minimum 1-3 months training at the National or Regional level in Bridge Inspection and Maintenance. Further, Bridge Inspectors Post Graduation in Structural Engineering with minimum three years of experience may be given preference.

The routine inspection of minor bridges and culverts shall be the responsibility of junior level officers (say below the rank of Executive Engineer) while the routine inspection of major bridges shall be the responsibility of senior level officers (Executive Engineer and above).

6.4 Inspection Methods

The various methods for Bridge Inventory and Condition survey are given below:

i) **Field Inventory & Visual Condition Survey**

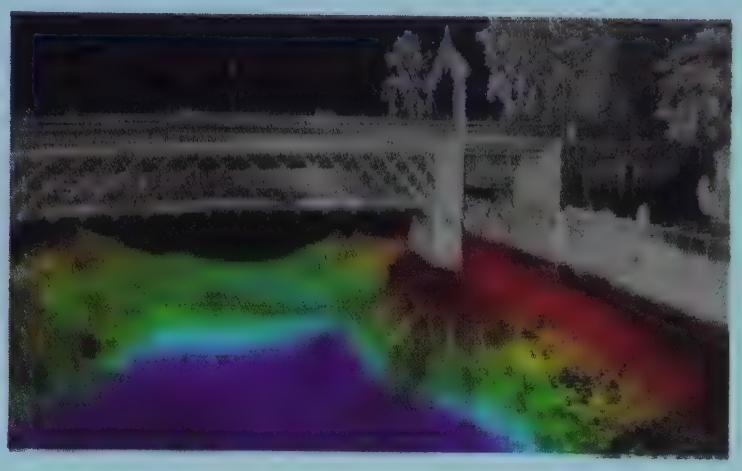
ii) **Photo/Video Log**

iii) **Integrated GPS/GIS Mapping Systems-NSV & MBIU**

iv) **Aerial Satellite Photography**

v) **Terrestrial Laser Scanning**

vi) **Mobile/ Airborne LiDAR**



vii) **Drones**

viii) **Robots**

The choice of the method may be based on the objectives, requirement, time & fund availability etc.

6.5 Bridge Inspection Reports

All the components of the bridges are to be inspected during the various inspections and the details to be complied in various proformae as given in **Appendix-IV**. Accordingly, the bridge inspection report shall be prepared and maintained for all inspections component wise indicating all the distresses seen including their location, extent & severity corresponding to every bridge component and is to be ascertained based on actual measurements at the site.

The first bridge inspection report shall be a detailed inspection to be carried out before opening to the traffic. Thereafter inspection reports of all routine, principal, emergent and underwater inspections carried out during the life of the bridge shall be maintained. The detailed inspection/investigation report shall be mandatory before taking any decision of maintenance, repair, rehabilitation, retrofitting, or replacement of any bridge.

All the bridges including culverts are to be inspected component wise and all observed deficiencies in accordance with the components shall be documented. Inventory data shall not be included or misinterpreted as inspection data. Inspection report shall be in accordance with the proformae as given in **Appendix-V**

The Sketches, photographs or video graphs should be used to illustrate the defects and other condition of the bridge components. The free hand sketches should be made during the inspection at the site itself the size and location of the defects should be dimensioned though the sketch itself need not be to scale. For taking photographs reference number of the bridge and the location of the defects may be written in colour at the appropriate place. Wherever particulars of the various bridge components are not available from the records the same are to be measure at site and both the inventory and condition survey to be completed.

The inspection reports should cover all the components to be listed in the proforma for inspection report. The inspecting officer must observe and report any structural deficiency, assess its seriousness, recognised and indicate areas of the bridge where any problems can be expected and suggest suitable preventive maintenance measures. Items needing urgent attention must be brought immediately to the notice of the Competent Authority for undertaking necessary remedial measures. The inspection report shall be appended with detailed observations/measurements at site in prescribed formats given in **Appendix-V**.

6.6 Tools and Equipment's for Inspection

These are an integral part of bridge inspection. They should be selected based on number and type of bridges to be inspected, the personnel available with appropriate standard professional training and level of inspection.

Generally routine inspection is based on visual assessment using conventional standard tools listed in **Appendix-VI.** Principal inspection will also have to rely primarily on visual assessment but may be supported by advanced tools and methods where it mandates detailed assessment including NDT. Multiple NDT test shall be avoided for the same type of distresses. Special inspection may also require advanced techniques and equipment apart from visual assessment.

Standard tools listed in **Appendix-VI** could be used along with the guidelines on field tests.

The Tools and Equipment's for Inspection (Typical tool kit with numbers in each kit) are given in **Table 6.1** below:

Table 6.1 Tools and Equipment's for Inspection

Sl. No.	Tools	Equipment	Numbers
1	Tools for Cleaning	Wisk broom, Wire brush, Scrapers (2 inch or 50 mm), Flat bladed, screw driver, Shovel	3
2	Tools for Visual Aid	Binocular, Flashlight, Lighted magnifying glass, Inspection mirrors, Dye penetrate, Crack scopes, Vernier calipers	3
3	Tools for Inspection	Pocket knife, Ice pick, Hand brace and bits, Increment borer, Chipping hammer with leather holder, Plumb bob, Tool belt with tool pouch, Chain drag, Range pole / Thin steel rod to probe (8-20 mm diameter) emery papers, piano-wire	2
4	Tools for Measuring	Measuring tape 5 m, 30 m, 50 m and 100 m, Laser Measuring Device, Calipers, Optical crack gauge, Paint film gauge, Tilt meter and protractor, Thermometer, D- Meter (ultrasonic thickness gauge), Electronic Distance Meter (EDM), Line level and string line. 2-meter straight edge and calibrated wedge for measuring rut depth Feeder Gauges, micrometer gauges, calipers, torque winches Straight edge, protractor, spirit level Thermometers etc.	1
5	Tools for Documentation	Tablet, Note-Pad, Plastic jar, bags for keeping samples Clip-boards, ball- point pens or pencils and note book, Inspection forms, inspection reports	1
6	Tools for Access	Boat, Ladders, Ropes Hangers etc.	As per the Requirement

7	Miscellaneous equipment	"C"-clamps, Penetrating oil, Insect repellent, Wasp and hornet killer, First-aid kit, Dust masks or respirators. A box of chalk for marking, markers clamp	These should be provided as per Man power deployed during inspection
8	Safety Tools	PPE	These should be provided as per Man power deployed during inspection
9	Visual Aids	Inspection mirror, binoculars, magnifying glass, Camera, camera flash light etc.	

Some of the photographs tools for access are given below:

6.7 Safety Aspects for Inspectors

The activities during the inspection of the bridges shall be planned in detail including sequence of inspection; advantage shall be taken of any situation like closure of traffic lanes of road works etc. Where mobile bridges inspection unit is decided to be used for the inspection care should be taken beforehand so as to use mobile inspection unit as it shall obstruct at least one lane of traffic on the bridges. The charges for the inspection shall be based on type, width and span length of bridges of similar kind and not per km length of the road.

The inspection of the foundation involving underwater inspections, the inspection cage should have proper lighting and safety devices and needs to be carried out by trained divers.

It is necessary to have suitable inspection platforms or movable gantries or truck mounted cantilever arms to enable the inspector to go underneath the bridge and observe the structure. The inspection equipment should be capable of reaching the bearing areas.

Modern techniques like Photos or videography, drones, MBIU etc. may be used for the inspections based on the necessity and site requirements.

Following safety aspects shall be ensured during the bridge inspection:

i) Traffic:

a) While walking on the bridge and its approaches, it is necessary to keep an eye on the traffic.

b) It is better to carry warning sings like DANGER, WORK IN PROGRESS, SLOW, etc. and place them so as to warn drivers.

c) It is better to wear bright coloured uniform and helmet, preferably yellow.

d) It is better to protect work area with cones and ask the assistant to control traffic.

Traffic may be stopped for a short while, if required

ii) Dangerous Spots:

a) Small bridges over shallow water could be inspected alone. Otherwise always take someone with you to make sure that you are safe.

b) Always a rope and a safety harness should be carried with you

c) Never go into dangerous places without assistance.

d) Keep a watch on insects, reptiles or animals or birds which can cause harm. This is especially so after floods,

e) Before going into closed spaces like inside of a box-girder, keep the manhole covers off for a long time before you enter. Poisonous gases can cause death. Always keep somebody standing outside, ready to help.

iii) Chemicals:

Most chemicals are toxic and proper care must be taken while using those.

CHAPTER 7

PRIORITIZATION OF BRIDGES FOR MAINTENANCE

7.1 Introduction

It is necessary to maintain bridges in traffic-worthy condition with requisite levels of safety and serviceability. To use the available funds for bridge maintenance scientifically and rationally maintenance/management strategy need to be developed.

Bridge maintenance is a specialized and expensive exercise. Before allocating resources for the maintenance of bridges, it is necessary to ascertain their present condition, their immediate and future maintenance requirements. Reliable data on the history of bridge condition and maintenance are of prime importance to the development of the maintenance strategy.

Moreover, criteria for rating of various components of the bridge and to assess the overall condition of the bridge in terms of Bridge Health Index (BHI) needs to be evolved. The condition of the bridges depends upon the types of distress, their extent, severity etc. which shall be used for the overall assessment of bridge condition.

The use of indices is one of the easiest means of determining the priority of bridge maintenance. Ascertaining the relative importance of bridge components is a prime requirement in the development of the indices. Indices are generally use for the preliminary ranking and once the raking is decided detailed analysis like, LCC, NPV, BC Ratio etc. being carried out for efficient/optimal utilization of resources.

Across the world, the aim of Bridge Health Indices (BHI)/Maintenance Priority Indices (MPI) remains the same which is to predict the present status of the bridge condition, the principles and approaches behind developing them are quite different. It all depends on the work culture of an organization and objective to be achieved. Every component/element of the bridge is a necessary unit of the bridge. However, their importance from the point of view of whole structures varies and must be accounted for assessment of the overall condition of bridge. Accordingly, BHI and MPI are being introduced taking into consideration the objective of uniform assessment and prioritization across the country.

7.2 Bridge Health Index (BHI)

In order to establish the overall bridge condition, relative importance of bridge components and every possible type of distress should be taken in to consideration. Accordingly, the following methodology is used for the development of BHI:

i) Classification of bridge component in accordance with their functionality

ii) Relative Importance of Bridge Components (Main & corresponding Sub-components)

iii) Classification of distress type in accordance with the Condition states

iv) Mathematical Model for BHI

v) Illustrative Example

7.3 Bridge Components and Relative Importance

The bridge components have been identified and grouped into seven categories based on the literature, prevalent bridge management systems, IRC codes and discussion with the experts in India namely:

(i) Approaches, (ii) Substructure, (iii) Waterway/channel, (iv) Foundation, (v) Superstructure, (vi) Appurtenances/auxiliary works and (vii) Bearings

The weights for the bridges can be established by suitable methods like Delphi, AHP, ANP etc. For the proposed various weights AHP has been used based on a detailed questionnaire survey. If so desired/required bridge components may be rearranged or added in the list and their relative importance can be assigned. Only requirement is to have the overall percentage of the weights shall be 100. The main bridge components and corresponding sub-components along with their relative importance are given in **Table 7.1**

Table 7.1 Relative Weights of Bridge Component and their Subcomponents

Sl. No	Bridge component	% weights	Bridge sub-component	% weights in a group	Overall %*weights
1	2	3	4	5	6
	C1-Approaches	3.6	C1.1 Alignment	16.0	0.58
			C1.2 Signages	5.8	0.21
			C1.3 Embankment/cutting	12.9	0.46
			C 1.4 Railing/crash barriers/guard stones/ parapet	15.2	0.55
			C 1.5 Approach slab	9.7	0.35

			C 1.6 Approach joint	9.9	0.36
			C1.7 Side drains	10.3	0.31
			C1.8 Slope protection	20.1	0.72
2	C-2 Substructure	18.0	C2.1 Abutment	14.2	2.55
			C2.2 Abutment Cap	11.1	2.00
			C2.3 Dirt wall	5.2	0.94
			C2.4 Weep holes	4.5	0.81
			C2.5 Wing walls	7.1	1.28
			C2.6 Abutment protection works	9.0	1.62
			C2.7 Pier	21.8	3.92
			C2.8 Pier cap	14.6	2.63
			C2.9 Pier protection works	12.5	2.25
3	C-3 Waterway/channel	5.8	C3.1 River/channel bed	4.0	0.23
			C3.2 Guide bunds	13.0	0.75
			C3.3 Spurs	8.4	1.24
			C3.4 Retaining wall	15.0	0.87
			C3.5 Toe walls	7.6	0.44
			C3.6 Floor/channel protection	12.0	0.70

			C3.7 Apron	11.3	0.65
			C3.8 Curtain/cutoff walls	14.7	0.85
			C3.9 Ground/rock anchors	14.0	0.81
4	C-4 Foundations	32.7	C4.1Foundations (raft/open/pile/well)	66.0	21.58
			C4.2 Apron	13.9	4.55
			C4.3 Foundation protection	20.1	6.57
5	C-5 Superstructure	21.7	C5.1 Girders/Main beams	35.0	7.60
			C5.2 Cross beams/diaphragms	14.2	3.10
			C5.3 Articulation	12.7	2.75
			C5.4 Deck slab	15.1	3.28
			C5.5 Cantilever slab	13.2	2.85
			C5.6 Joints	9.8	2.12
6	C-6 Appurtenances/ Auxiliary works		C6.1 Wearing surface	7.9	0.32
			C6.2 Footpaths	7.3	0.30
			C6.3 Expansion joints	17.8	0.73
			C6.4 Prestressing elements (anchorages etc.)	18.7	0.77

		4.1	C6.5 Median	4.8	0.20
			C6.6 Kerbs/cornices	4.6	0.19
			C6.7 Light posts	3.7	0.15
			C6.8 Drainage spouts	7.4	0.30
			C6.9 Parapet/railing/guard stones/crash barrier	11.9	0.49
			C6.10 Waterproofing system	7.6	0.31
			C6.11 Painting system	4.3	0.18
			C6.12 Utilities	3.9	0.16
7	C-7 Bearings	14.0	C7.1 Bearings	50.0	7.00
			C7.2 Bearing seats/caps	25.4	3.56
			C7.3 Earthquake restraints/Stoppers	24.6	3.44

***Value under column (6) is equal to Value under column (3) multiplied by percentage weight under column (5)**

Brief Description of AHP: For the determination of relative weights there are various methods. For example, the experts could be asked to rank the various components directly on 0-10 or 0-100 scales; the experts could be asked to provide their responses on a specific scale, such as the Likert scale and the weights could be worked out based on their responses; or the experts could be asked to provide their responses on the pairwise comparison of various components, as in the case of the Analytical Hierarchy Process (AHP). The AHP is a type of decision theory which has proved to be popular because of its mathematical properties and simple implementation. AHP is capable of handling quantitative, qualitative, tangible and intangible criteria. Thus, AHP has been selected to compute the relative weights of different bridge components and their subcomponents in a systematic manner. A questionnaire was

designed to elicit responses from Indian bridge experts on the computation of relative weights for different bridge components using the AHP. Respondents were asked to only fill in the absolutely essential columns of the pairwise comparison matrix, which was expanded later for analysis after collecting the responses. The respondents were requested to compare various bridge components mentioned earlier and their sub-components, in a pairwise manner on a nine-point scale that is 1 to 9 numbers mentioned.

7.4 Bridge Distresses Classification as per Condition States

During the bridge inspection every possible distress is to be categorized in to five condition states defined in **Chapter 5** namely, I (Excellent); II (Good); III (Fair); IV (Poor); and V (Critical). The method of inspection may be visual or NDT but the extent and severity are to be measured at the site. The tentative range of values for the various distresses corresponding to the condition states for concrete bridges are given in **Table 7.2 & 7.3.**

Table 7.2 Distress Type and Range of Values Corresponding to Condition States of Bridge Components

Sl. No.	Distress type	Range of values for Condition States					
		Unit	I (Excellent)	II (Good)	III (Fair)	IV (Poor)	V (Critical)
1	Erosion	%	Nil	0-10	11-20	21-30	>30
2	Abrasion	%	<10	10-20	21-40	41-50	>50
3	Scour (depth) from Ground level	M	Nil	<0.25	0.26-0.50	0.51-1.0	>1.0
4	Vegetation	No/ %	Nil	2/<10-25	5/26-50	10/51-75	>10/ 75
5	Deformations (deflection/tilt)	mm	Nil	<5	5-10	11-50	>50
6	Honeycombing	%	Nil	<5	5-15	16-25	>25
7	Delamination	%	Nil	<5	5-15	16-25	>25
8	Spalling	%	Nil	<5	5-10	11-20	>20
9	Staining/scaling/leaching	%	Nil	<10	10-25	26-50	>50
10	Rust	%	Nil	<5	5-10	11-25	>25

11	Cracking (width)	mm	Nil	≤ 0.3	0.3-1.0	1.1-2	> 2
12	Exposed reinforcement	%	Nil	<5	5-10	11-15	>15
13	Reduction in area of reinforcement	%	Nil	<5	5-10	11-20	>20
14	Section loss	%	<5	5-10	11-15	16-25	>25
15	Efflorescence	%	Nil	<10	11-25	26-50	>50
16	Crushing	%	Nil	Nil	<5	5-10	>10
17	Rutting	mm	Nil	<10	10-25	26-50	>50
18	Unevenness	%	Nil	<5	5-15	16-25	>25
19	Degradation (wear and tear)	%	Nil	<10	10-20	21-50	>50
20	Missing elements	No.	Nil	<2	2-5	6-10	>10
21	Leaning/bulging	mm	Nil	<5	5-15	16-25	>25
22	Loose joints	No.	Nil	<2	3-5	6-8	>8
23	Undesired restraints	No.	Nil	Nil	1	2-3	>3
24	Marine boars	%	Nil	<10	10-25	26-50	>50
25	Inadequate drainage spots	No.	Nil	<2	3-5	6-8	>8
26	Silting	%	Nil	<10	10-25	26-50	>50

Table 7.3 Distress Types Corresponding to Condition States for Approaches/Wearing Course

Sl. No.	Distress type	Range of Values for Condition States					
		Unit	I (Excellent)	II (Good)	III (Fair)	IV (Poor)	V (Critical)
1	Alligator (Fatigue) cracking	%	Nil	1-5	6-15	16-30	>30
2	Longitudinal cracking	mm	Nil	≤ 5	6-10	11-20	>20
3	Transverse cracking	mm	Nil	≤ 5	6-10	11-20	>20
4	Block cracking	%	Nil	1-5	6-15	16-30	>30
5	Reflection cracking	mm	Nil	≤ 5	6-10	11-20	>20
6	Edge cracking	mm	Nil	1-5	6-15	16-30	>30
7	Slippage	%	Nil	1-5	6-15	16-30	>30
8	Bleeding	%	Nil	<10	10-20	21-50	>50
9	Settlement/ Bumps/ Heave	No./ mm	Nil	1/≤15	2/ 16-30	3-5/ 31-50	>5/ >50
10	Potholes	No.	Nil	<2	2-5	6-8	>8
11	Patching	%	Nil	0-5	6-15	16-30	>30
12	Pumping	%	Nil	<10	10-15	16-25	>25

13	Ravelling	%	Nil	≤25	25-50	51-75	>75
14	Rutting	mm	Nil	<5	5-15	16-25	>25
15	Shoving/corrugation	mm	Nil	<5	5-10	11-25	>25
16	Rain cuts	No.	1-5	6-10	11-15	16-20	>20
17	Lane/Shoulder drop	mm	Nil	<25	25-50	51-100	>100
18	Missing elements	No.	Nil	<5	5-10	11-15	>15
19	Erosion	%	<5	5-15	16-30	31-50	>50
20	Silting of Joints	%	<5	5-15	16-30	31-50	>50
21	Damage to drainage components like wall etc.	% severity	<10	10-25	26-45	46-60	>60
22	"D" Cracking	m^2	Nil	<5	5-10	11-15	>15
23	Faulting	mm	Nil	<5	5-10	11-25	>25
24	Joint damage	%	Nil	<10	10-30	31-50	>50
25	Blowup	mm	Nil	<6	6-25	26-50	>50
26	Scaling	%	<5	5-15	16-30	31-50	>50
27	Pop out	m^2	Nil	<3	3-6	7-9	>9
28	Punch out	mm	Nil	<75	75-110	111-150	>150

29	Lane/ Shoul der Separ ation	mm	Nil	<10	10-20	21-50	>50
30	Shattered Slab	No.	Nil	<3	3	4-6	>6
31	Corner Spalling	mm	Nil	<25	25-35	36-50	>50
32	Vegetation	%	Nil	<25	25-50	51-75	>75
33	Corner Break	%	Nil	<25	25-35	36-50	>50
34	Polished Aggregate	%	Nil	<20	20-45	46-70	>70

These values are based on the literature review and feedback by the experts. However, range values may be reviewed again with available guidelines especially Ministry and IRC and suitably modified in future.

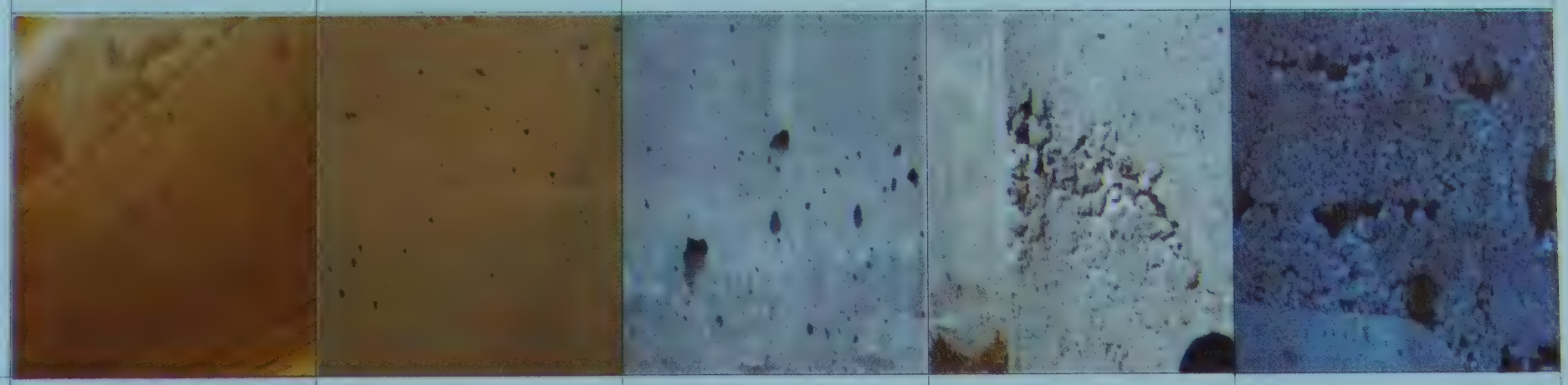
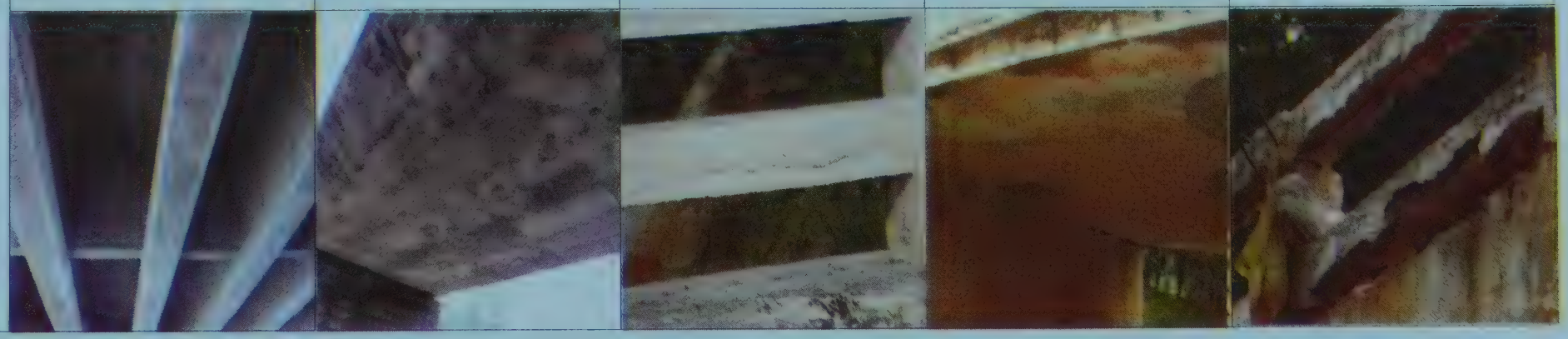
In addition to the description for condition assessment & range of values for distress types photographs corresponding to **Table 7.2** and **Table 7.3** are also given for ready reference of inspector as per **Table 7.4** & **Table 7.5** respectively.

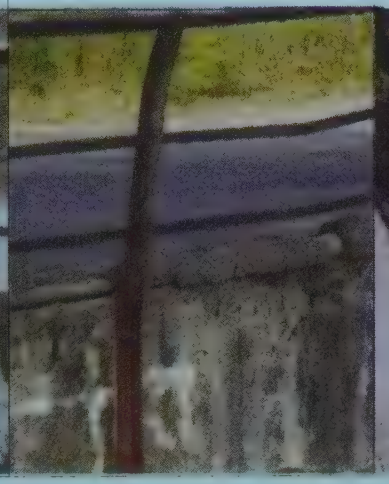
Ranges of values have been arrived after detailed literature survey and feedback from the bridge experts representing various bridge committees of IRC. For other materials and also for state of the art bridges like Cable Stayed bridges, Extra-dosed bridges and Suspension Bridges table may be required to be updated or modified.

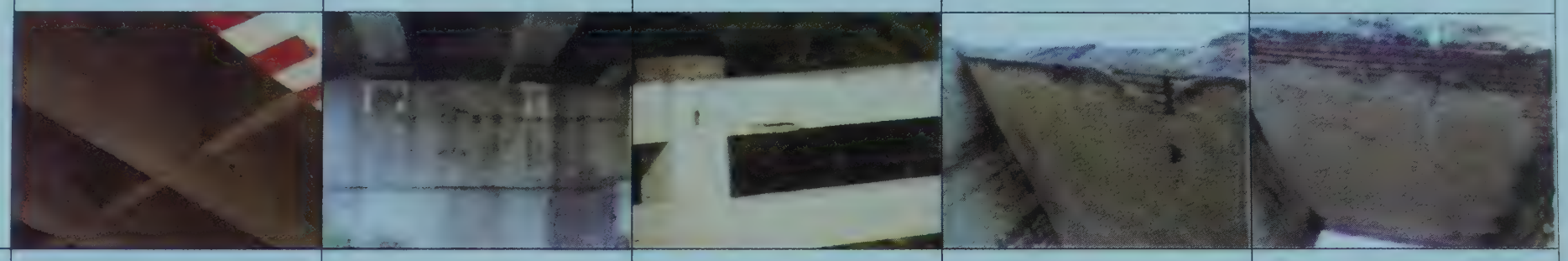
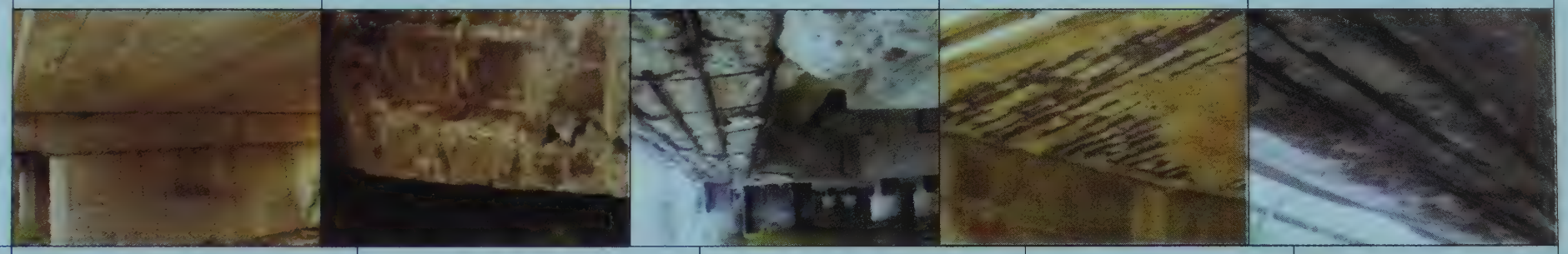
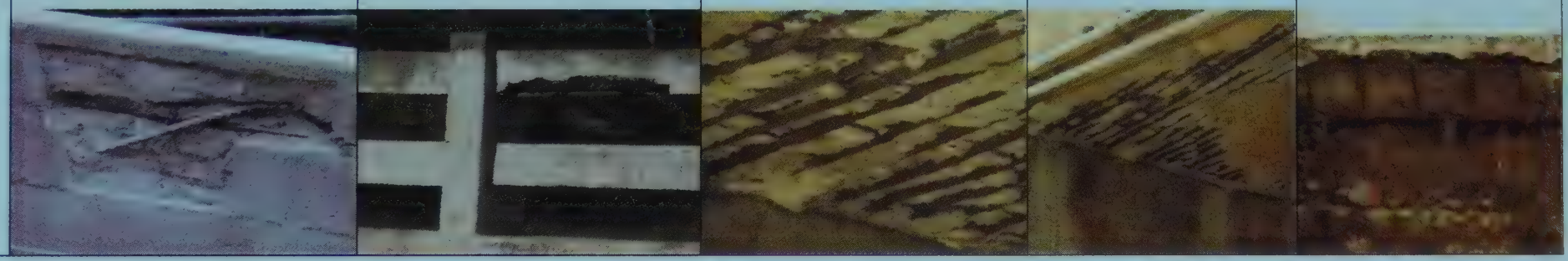
Bridge inspector has to see the member, type of material, types of distresses, location of the distress, extent of distress, severity of distress as per the actual measurement at site and then assign corresponding condition states for all components.

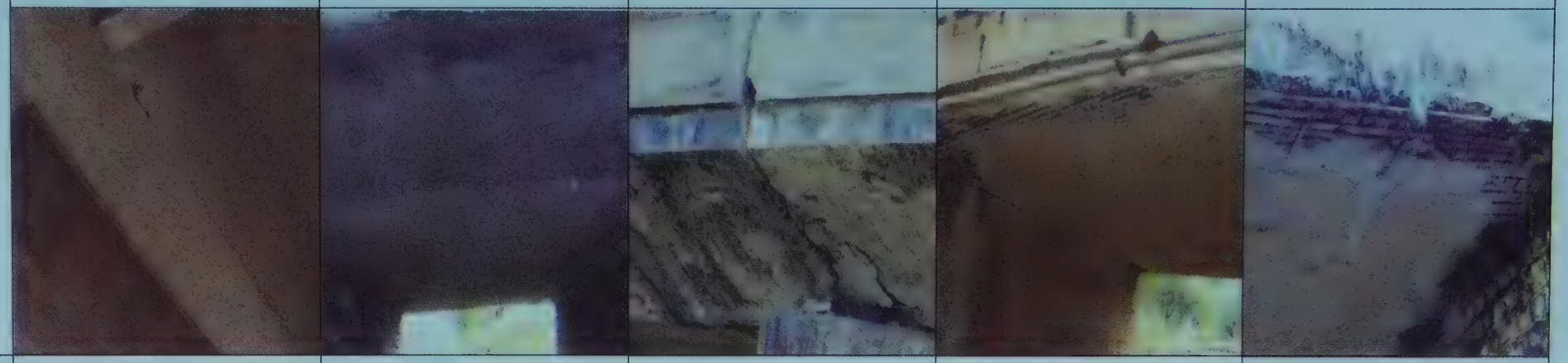
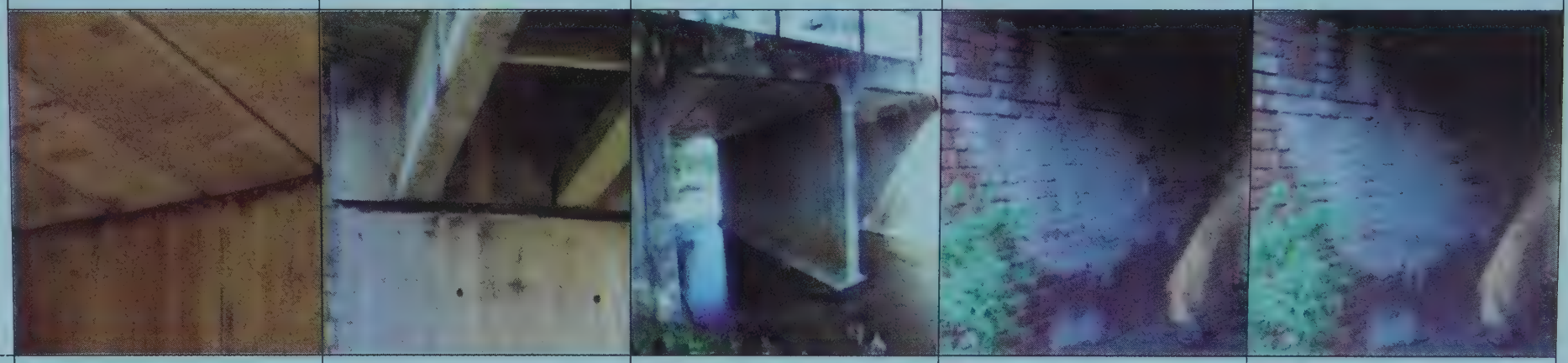
Table 7.4: The Photographs for the Various Condition States of Distress Types of Bridge Components

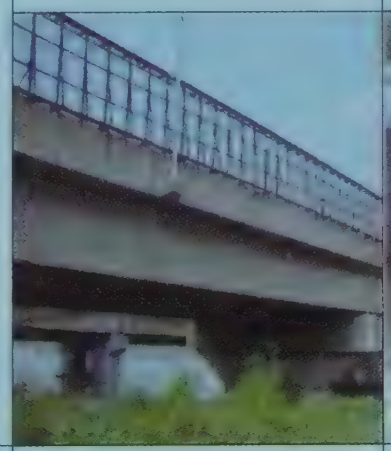
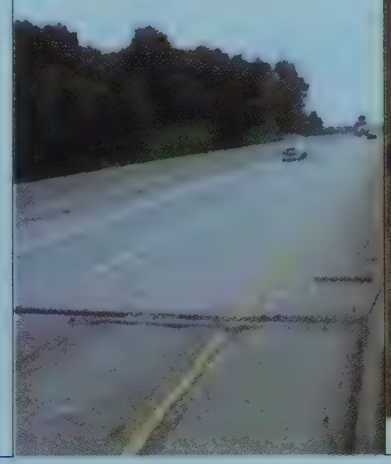
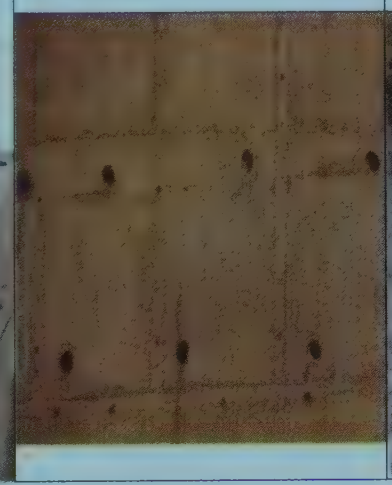
Sl. No.	Distress Type	Unit	Condition State				
			I	II	III	IV	V
1	**Erosion**	%	Nil	0-10	11-20	21-30	>30
2	**Abrasion**	%	<10	10-20	21-40	41-50	>50
3	**Scouring**	m	Nil	<0.25	0.26-0.50	0.51-1.0	>1.0

4	**Vegetation**	No/ %	Nil	2/<10-25	5/26-50	10/51-75	>10/ 75
5	**Honey Combing**	%	Nil	<5	5-15	16-25	>25
							
6	**Delaminatio n**	%	Nil	<5	5-15	16-25	>25
							

7	**Spalling**	%	Nil	<5	5-10	11-20	>20
8	**Staining, Scaling or Leaching**	1 %	Nil	<10	10-25	26-50	>50
9	**Rust**	%	Nil	<5	5-10	11-25	>25
							

10	**Cracking**	mm	Nil	≤ 0.3	0.3-1.0	1.1-2	> 2
11	**Exposed Reinforcement**	%	Nil	<5	5-10	11-15	>15
							
12	**Corrosion Depth of pitting excluded**	mm	<0.1	0.1-0.3	0.31-0.5	0.51-1.0	>1
							
13	**Reduction in area of reinforcement**	%	Nil	<5	5-10	11-20	>20
							

14	**Section Loss**	%	<5	5-10	11-15	16-25	>25
							
15	**Efflorescence**	%	Nil	<10	11-25	26-50	>50
							
16	**Rutting**	mm	Nil	<5	5-15	16-25	>25

17	**Degradation (Wear & Tear)**	%	Nil	<10	10-20	21-50	>50
18	**Tilting**	mm	Nil	Up to 1 in 100	Up to 1 in 75	Up to 1 in 60	>1in 60
							
19	**Inadequate Drainage Spot**	No.	Nil	<2	3-5	6-8	>8
							

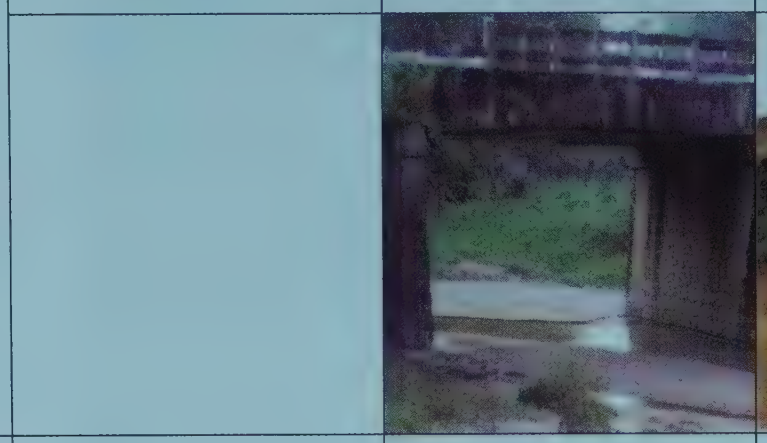
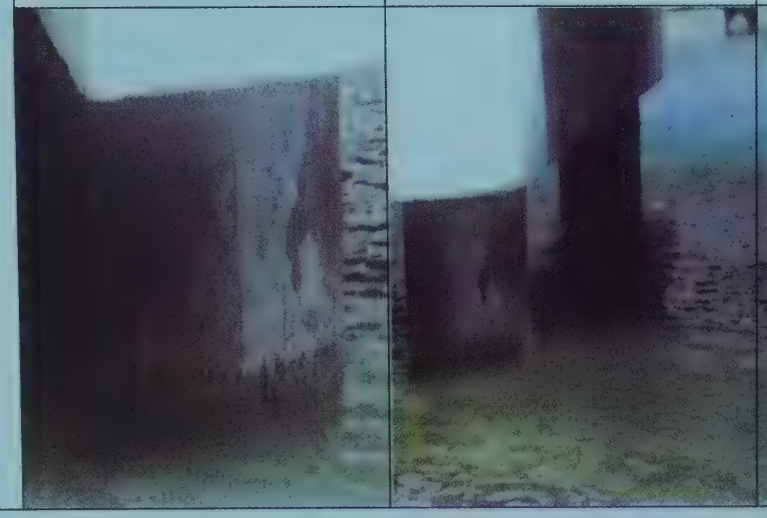
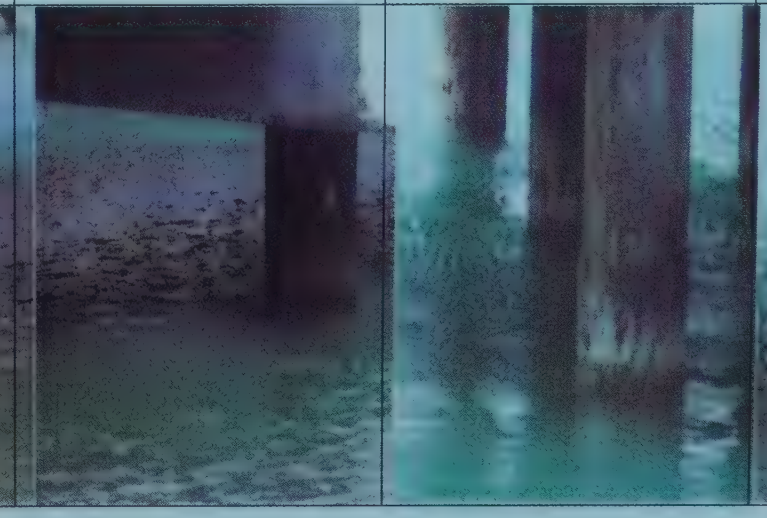
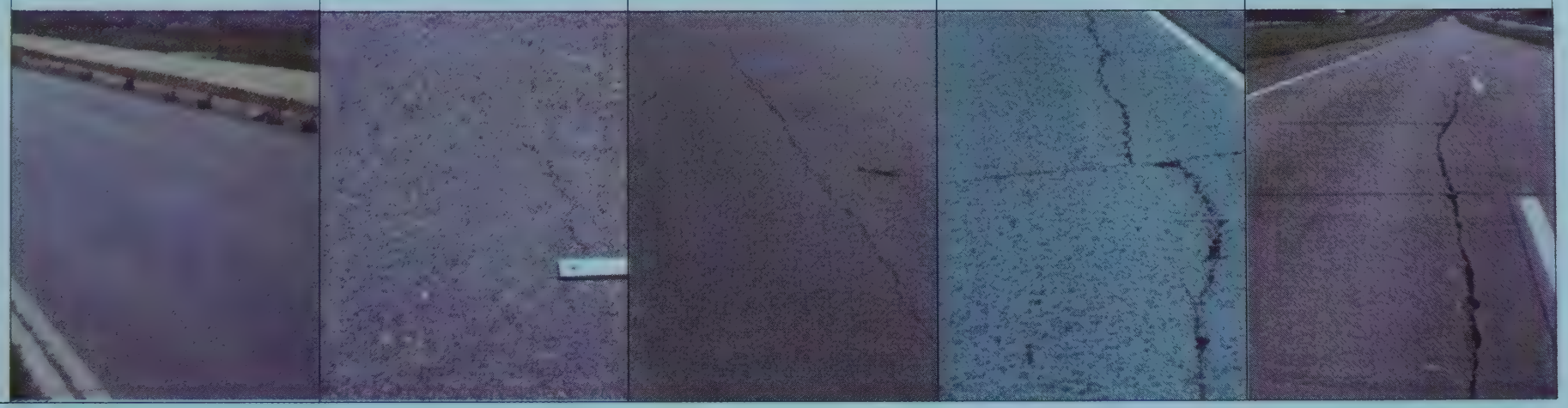
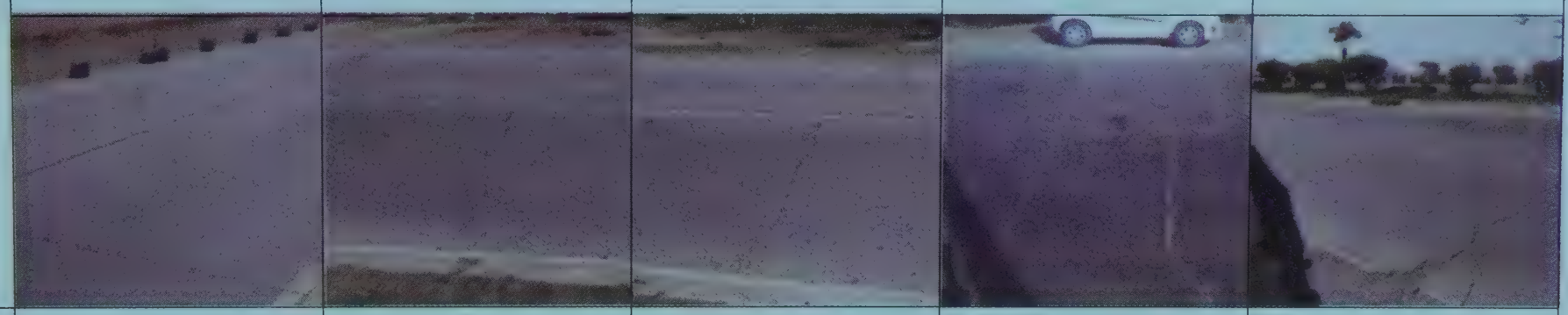
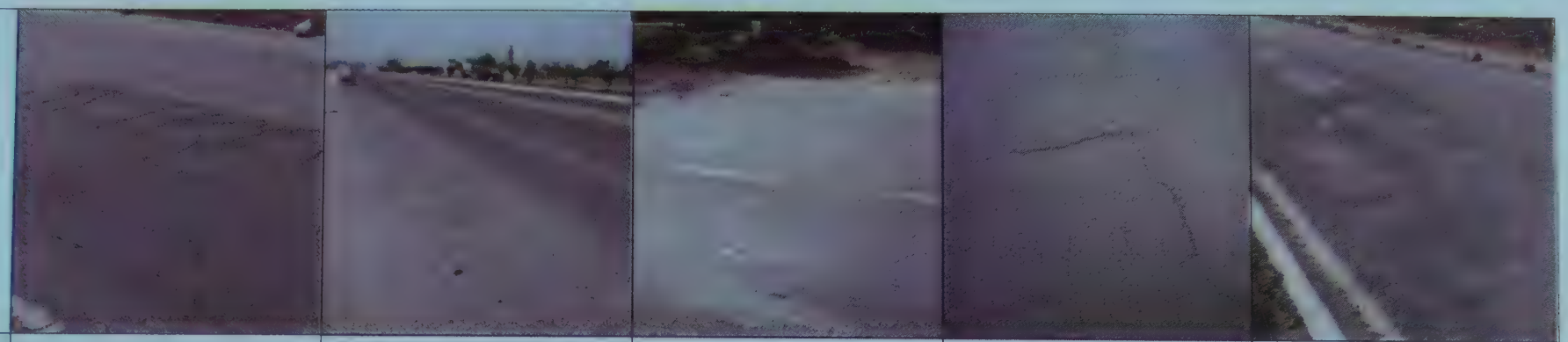
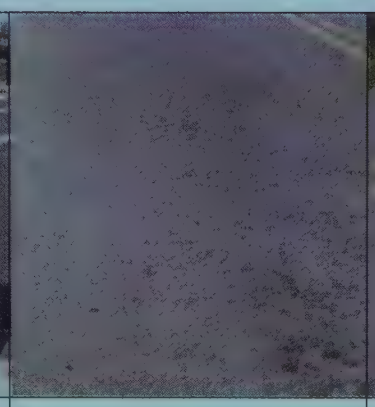
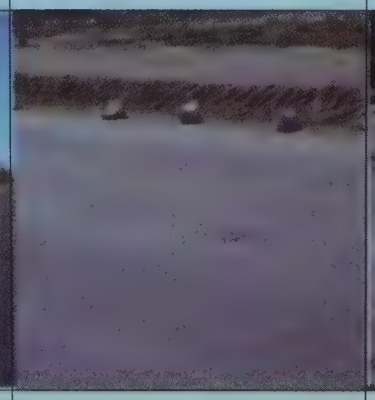
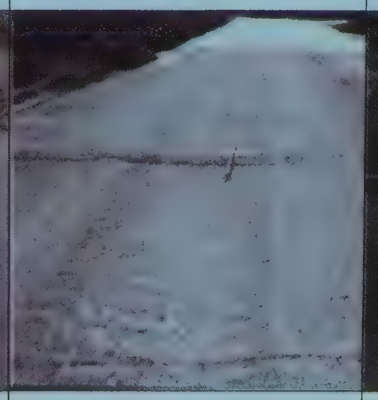
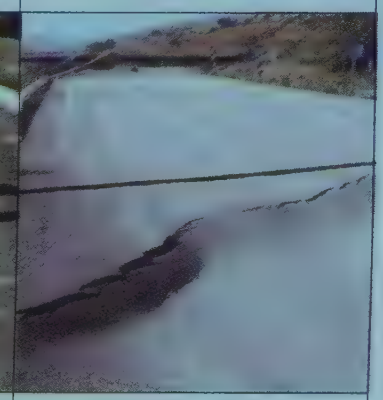
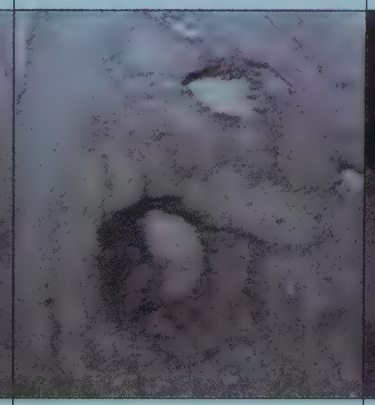
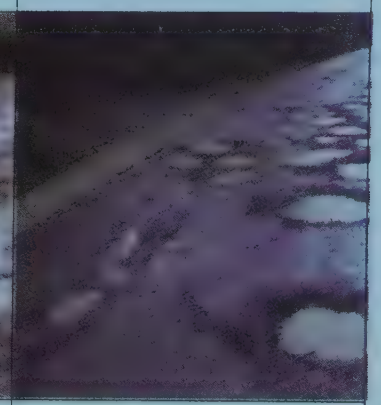
20	**Silting**	%	Nil	<10	10-25	26-50	>50
							
21	**Marine Boars**	%	Nil	<10	10-25	26-50	>50
							

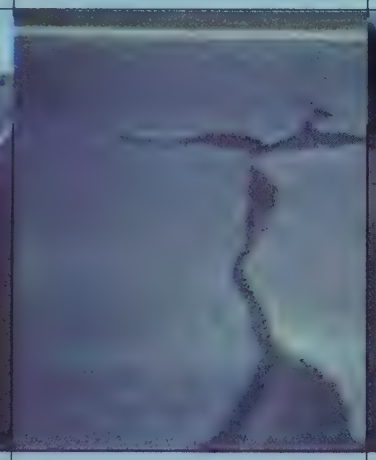
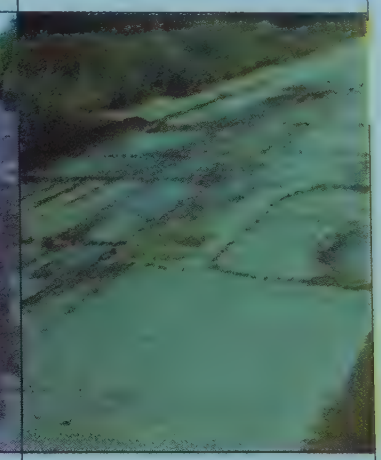
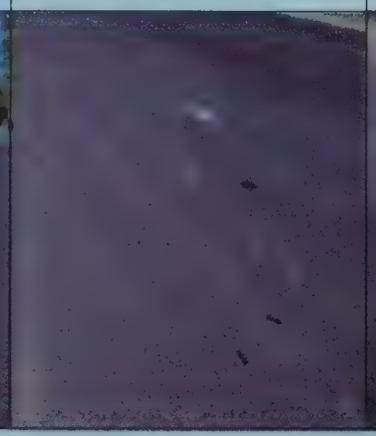
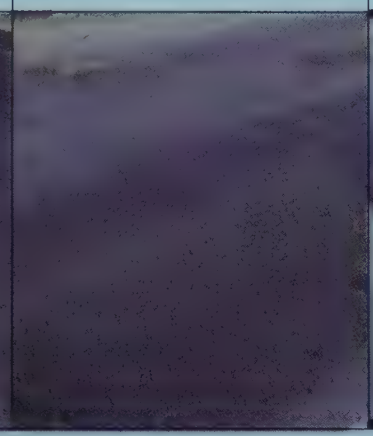
Table 7.5: The Photographs for the Various Condition States of Distress Types for Approaches/Wearing Course

Sl. No.	Distress Type	Unit	Range of Values for Condition States				
			I (Excellent)	II (Good)	III (Fair)	IV (Poor)	V (Critical)
1	**Alligator Cracking**	%	Nil	1-5	6-15	16-30	>30
2	**Longitudinal Cracking**	mm	Nil	≤ 5	6-10	11-20	>20
							

Sl. No.	Distress Type	Range of Values for Condition States					
		Unit	I (Excellent)	II (Good)	III (Fair)	IV (Poor)	V (Critical)
3	**Transverse Cracking (Flexible)**	mm	Nil	≤ 5	6-10	11-20	>20
	Transverse Cracking (Rigid)	mm	Nil	≤ 5	6-10	11-20	>20
							
4	**Block**	%	Nil	1-5	6-15	16-30	>30

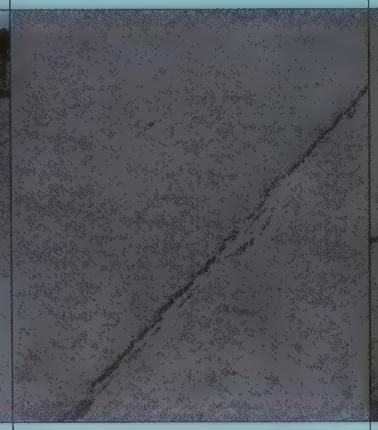
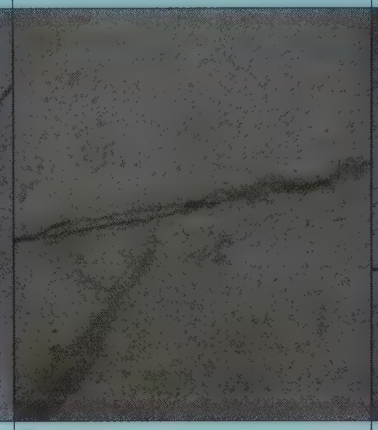
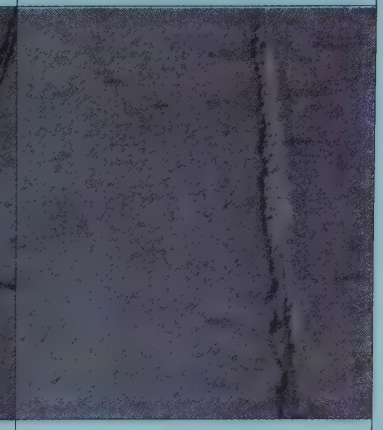
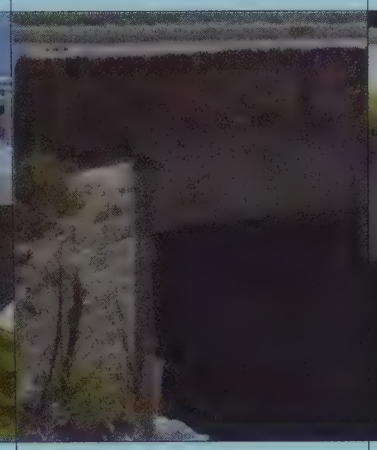
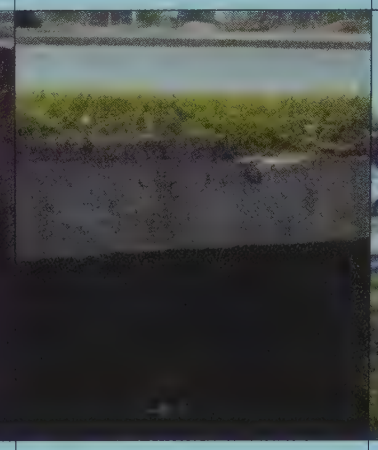
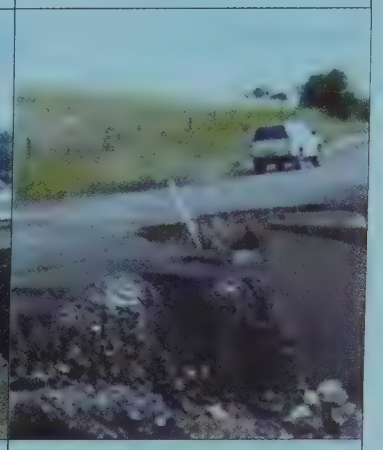
	Cracking						
5	**Edge Cracking**	mm	Nil	1-5	6-15	16-30	>30
6	**Slippage**	%	Nil	1-5	6-15	16-30	>30
7	**Bleeding**	%	Nil	<10	10-20	21-50	>50

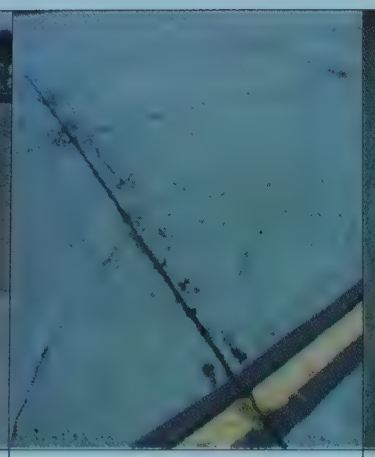
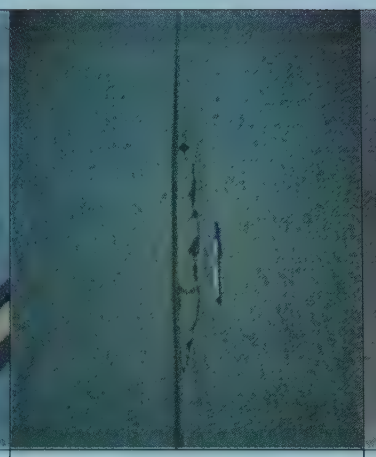
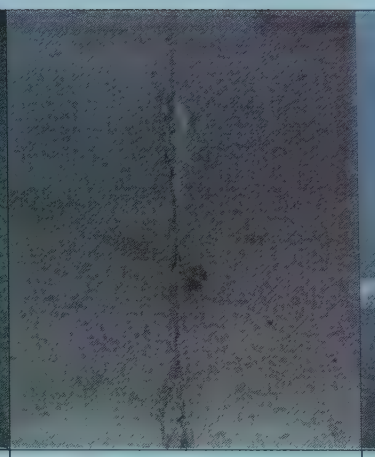
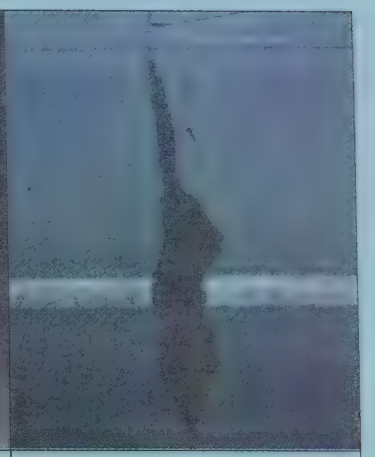
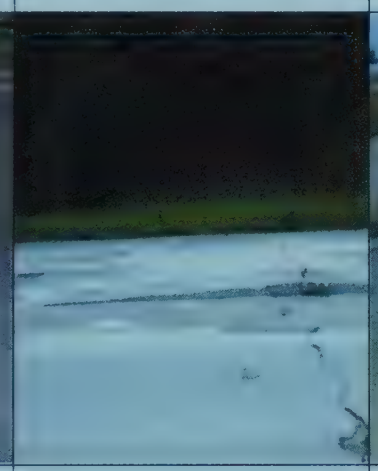
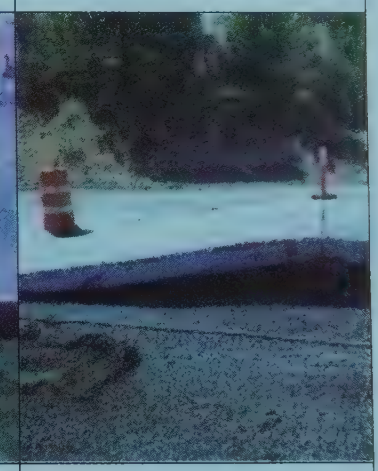
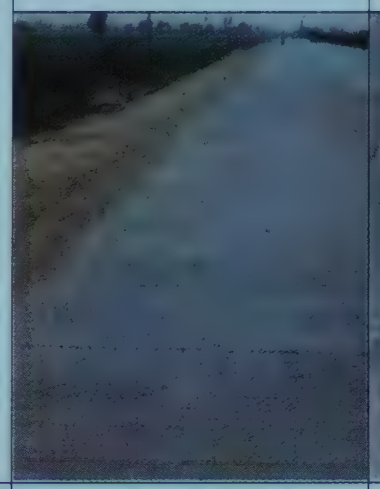
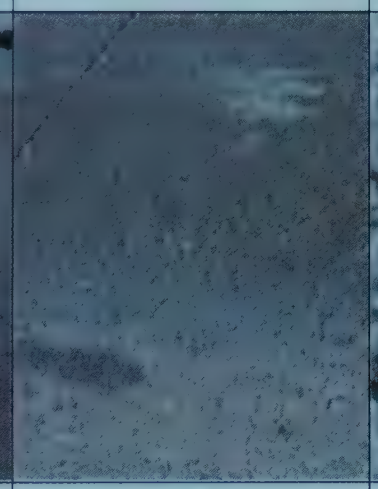
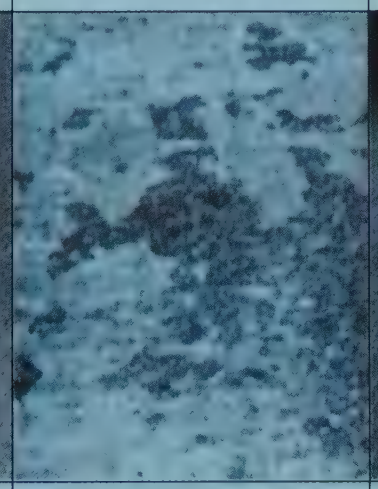
							
8	**Settlement/ Bumps/ /Heave**	No. or mm	Nil	1/≤15	2/16-30	3-5/31-50	>5/>50
							
9	**Potholes**	No.	Nil	<2	2-5	6-8	>8
							
10	**Patching**	%	Nil	0-5	6-15	16-30	>30

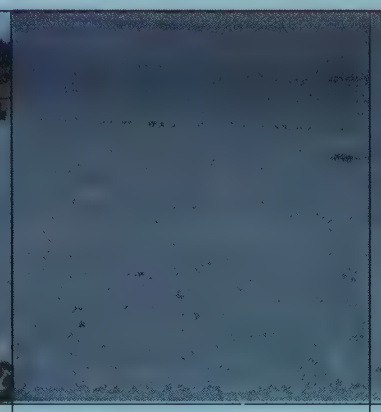
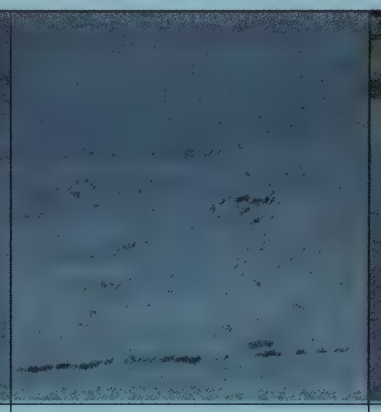
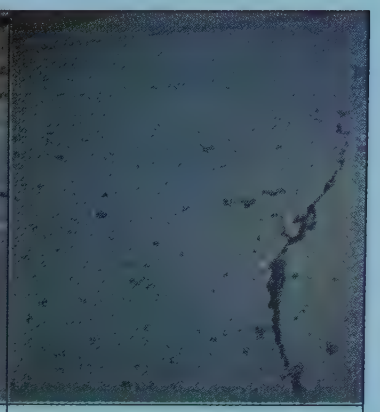
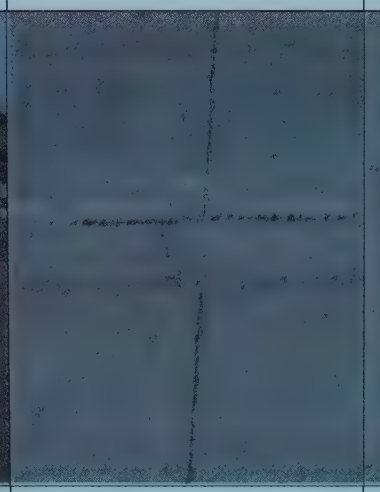
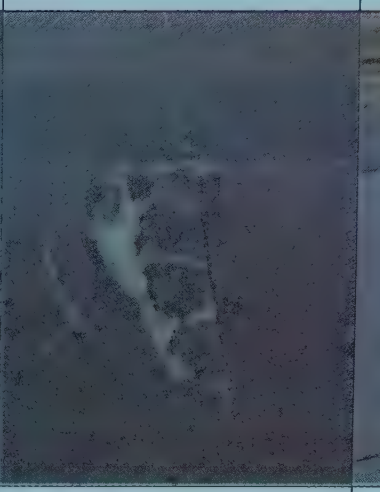
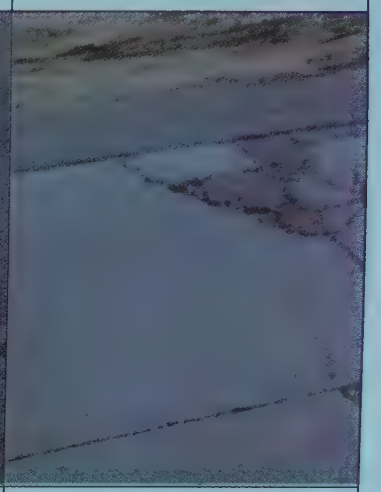
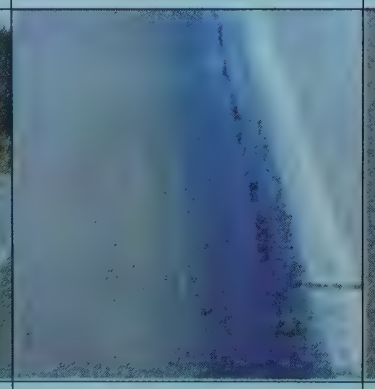
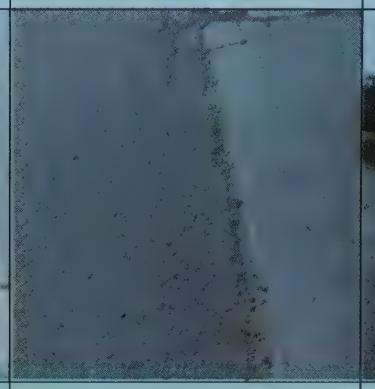
11	**Pumping**	%	Nil	<10	10-15	16-25	>25
							
12	**Ravelling**	%	Nil	≤25	25-50	51-75	>75
							

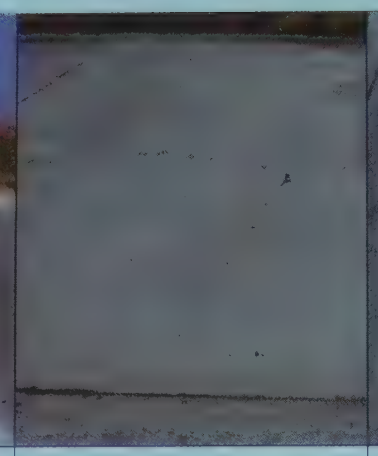
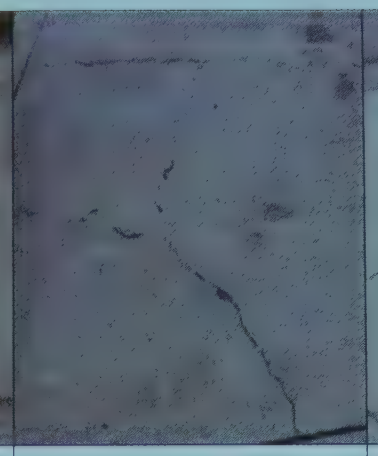
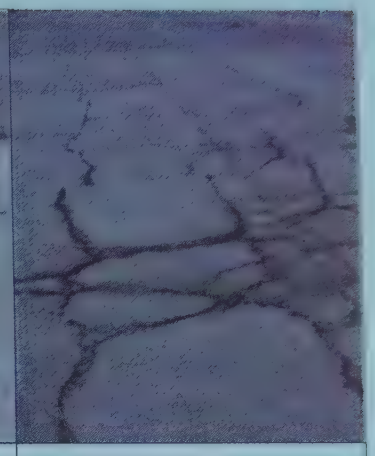
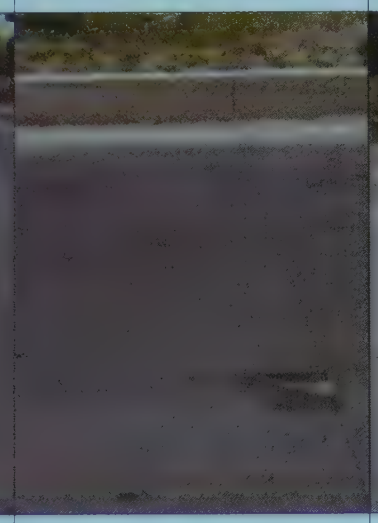
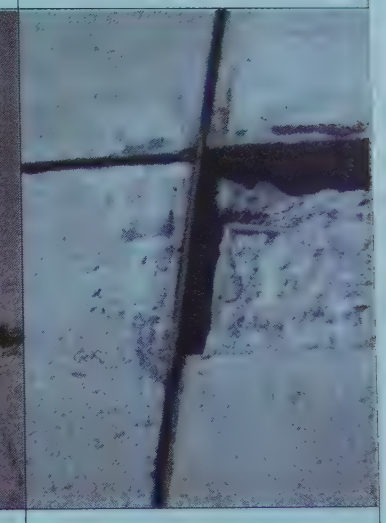
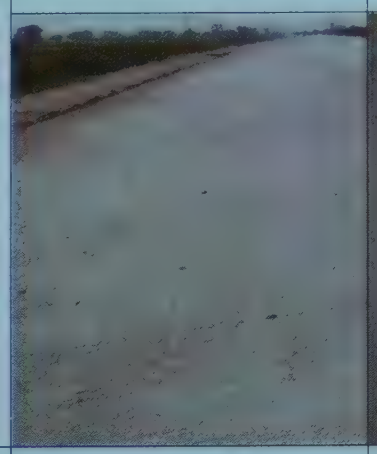
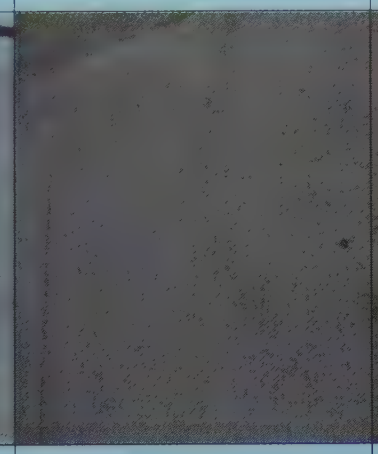
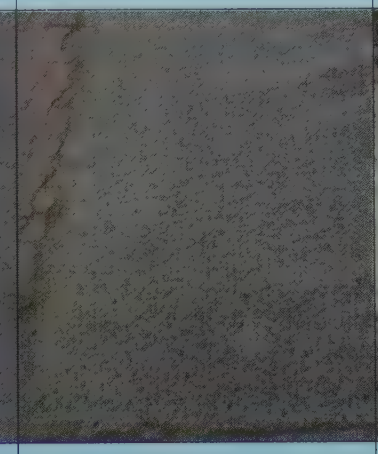
13	**Rutting**	mm	Nil	<5	5-15	16-25	>25
14	**Shoving/ Corrugation**	mm	Nil	<5	5-10	11-25	>25
15	**Rain Cuts**	No.	1-5	6-10	11-15	16-20	>20

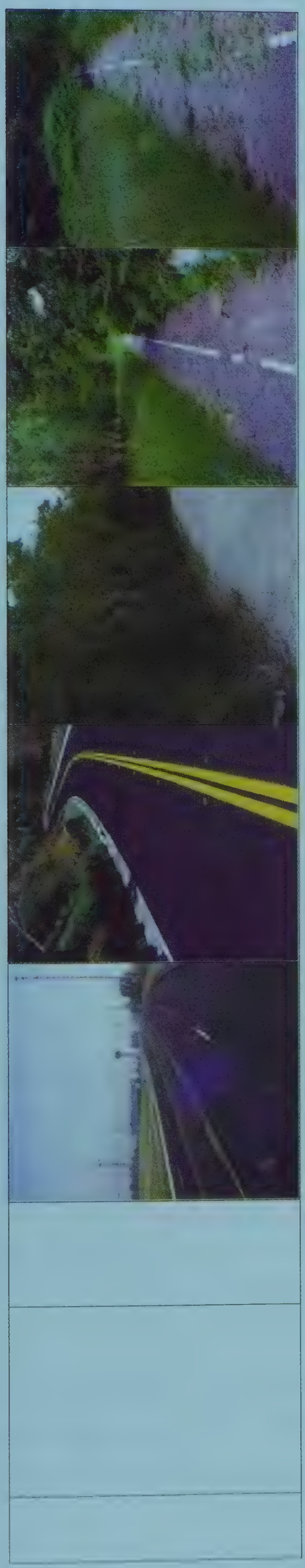
16	**Lane/ Shoulder drop**	mm	Nil	<25	25-50	51-100	>100
17	**Erosion**	%	<5	5-15	16-30	31-50	>50

18	**Silting of Joints**	%	< 5	5-15	16-30	31-50	>50
							
19	**Damage to drainage components like wall etc.**	% severity	<10	10-25	26-45	46-60	>60
							
20	**Faulting**	mm	Nil	<5	5-10	11-25	>25
21	**Joint**	%	Nil	<10	10-30	31-50	>50

	damage						
22	**Blowup**	mm	Nil	<6	6-25	26-50	>50
							
23	**Scaling**	%	<5	5-15	16-30	31-50	>50
							
24	**Pop out**		Nil	<3	3-6	7-9	>9

		m^2					
25	**Corner Break**	%	Nil	<25	25-35	36-50	>50
							
26	**Lane/ Shoulder Separation**	mm	Nil	<10	10-20	21-50	>50
							
27	**Shattered**	No.	Nil	<3	3	4-6	>6

	Slab						
28	**Corner Spalling**	mm	Nil	≤25	26-35	36-50	>50
							
29	**Polished Aggregate**	%	Nil	<20	20-45	46-70	>70
							
30	**Vegetation**	%	Nil	<25	25-50	51-75	>75



7.5 Bridge Condition Index Model

Following mathematical model for Bridge Health Index has been proposed (Equations 1 to 3) combining the relative weights of bridge components, description of condition states and quantification of the types of distresses corresponding to condition states.

$$BHI = \frac{\sum_{i=1}^{N} W_i \times CI_i}{\sum_{i=1}^{N} W_i} \qquad (1)$$

$$CI_i = \frac{\sum_{j=1}^{n} W_j \times CS_j}{\sum_{j=1}^{n} W_j} \qquad (2)$$

and

$$CS_j = \frac{\sum_{k=1}^{d} (100 - 100 \times S_k)}{d} \qquad (3)$$

where BHI= Bridge Health Index, W_i = Weights of bridge component 'i'; CI_i= Condition Index of bridge component 'i' CS_j= Condition State of sub components; N = Number of major bridge components of a bridge (1 to7); n = Number of sub-component corresponding to major bridge components; W_j = Weights of sub-bridge components, d = Number of distress types noticed (**Table 7.4** & **Table 7.5**) and S_k = reduction coefficient corresponding to condition state of sub component. The Values of S_k for the condition states namely, I (Excellent), II (Good), III (Fair), IV (Poor) and V (Critical) are taken as *0*, *0.25*, *0.5*, *0.75* and *1.0* respectively.

Example: In case for bridge under consideration, in deck slab four distress types namely honey combing, spalling, exposed reinforcement and efflorescence have been observed. After the measurement of extent and severity it was found that the corresponding Condition States are II, III, II, I. The value of corresponding reduction factor will S_k be for Condition State II is 0.25, III is 0.5 and for I is 0 is respectively. Accordingly, the CS_j of bridge is computed as follows.

CS_j = [2(100-100*0.25) + (100-100*0.5) + (100-100*0)]/4 CS_j =(150+50+0)/4=50.0

Likewise CS_j shall be calculated and used for determination of CI and BHI considering the relative weights of components and corresponding sub-components of bridge.

7.5.1 Note with regards to BHI & Star Rating

The value of the BHI varies from 0-100. Towards zero signifies the worst case of bridge condition while towards 100 indicates the Excellent. For number of bridges having BHI values may be put in descending/ascending order and bridge shall be selected on the basis of value of BHI for ranking at network level.

In addition various bridge components for number of bridges which are in critical state may be separately prepared and appropriate decision can be taken for their maintenance and repairs. If the funds are very less compared to the requirement one can select only those components

which are observed to be in critical condition state depending on the extent and severity of distress.

BHI Model takes into consideration all the components within ROW. It takes in to account relative importance of various components that is their weights. It gives well defined description for condition assessment for various components. It takes into account every possible distress types which are affecting the condition of a particular bridge component. The condition assessment is based on the field measurement of distress types, extent and severity.

Although 60 **(Table 7.3** & **Table 7.4**) different types of distresses are enumerated there may be other distress types found during the inspection and condition survey. These distresses required to be categorised in to five condition states description given in **Table 5.1,** after measurement of extent and severity of distresses. Even the detailed investigations by NDT are to be categorized in to these five condition states only.

BHI shall be calculated for single span considering both abutments. In case of two span BHI shall be calculated for each span considering Abutment and pier. In case of multiple spans BHI shall be calculated for end span as well as intermediate spans considering piers. The lowest value of BHI amongst all span shall be consider BHI of the bridge.

If no apparent deficiencies found, the condition rating of Excellent shall be given to those bridge components. If there is no element found, the same shall be reported as Not Applicable (NA) and accordingly excellent condition rating shall be given for determination of BHI.

Generally, foundations shall not be visible and overall rating of foundation shall be assigned considering overall stability by observing the shift, tilt and displacement/deformations of superstructure and other components if any. It is natural that without foundation other components may not function as intended and accordingly reflected in condition rating.

There are some of the bridge components which are not currently accommodated in formulation of BHI. However, during the inventory and condition survey all the bridge components shall be covered and BHI shall be estimated by only selective components.

Bridges or Bridge Components may be classified on the basis of BHI values as below and star rating may be assigned.

Sl. No.	Value of BHI	Condition States of Bridge/Bridge Components	Bridge Star Rating
1	<20	Critical	One
2	21-40	Poor	Two
3	41-60	Fair	Three
4	61-80	Good	Four
5	81-100	Excellent	Five

7.6 Illustrative Example

For an illustrative example for the application of BHI an inspection data of Yamuna Bridge in Delhi have been presented. The inspection was carried out in around 2010-11 and data is for illustration purpose only.

The bridge consists of 13 spans over river Yamuna. Superstructure of the bridge consists of pre-stressed concrete girder and RCC slab. Substructure of the bridge consists of RCC piers and well foundation. Bearings are made up of mild steel and are plate and roller type. Condition states and the range of values of distress type along with the photographs were used for visual assessment of the condition states of various bridge components and their subcomponents.

The component wise results of visual inspection carried out are as given in **Table 7.6.** It was found during inspection that the four approach components namely, alignment, embankment, approach slab and approach joint were in excellent condition. Accordingly in **Table 7.6**, the entries under Column 4 are **I.** The railing was absent and thus entry corresponding to this subcomponent in column 4 of **Table 7.6** is **V**. The inspector observed that signages, side drains and slope protection were in good condition and thus in column 4 of **Table 7.6**, Condition State **II** has been entered corresponding to the three subcomponents of approaches.

Similar entries were made for all the bridge components based on the observations/inspection at site by the inspector. W_j for various subcomponents in **Table 7.6** has been taken from **Table 7.1**. CS_j in **Table 7.6** is derived from Equation-3 for various subcomponents. An illustration of computation of CS_j for Bridge Pier Cap is given below.

Pier cap is affected by Four distress types namely, exposed reinforcement, spalling, corrosion (all Condition State II with S_k value equal to 0.25) and staining (Condition State III, k = 0.50)

CS_j for Pier Cap = $\frac{3\times(100-100\times0.25)+1\times(100-100\times0.50)}{4}$ = 68.75. In similar way condition states and corresponding values of S_k were put in Equation-3 and thereafter BHI is calculated by using Equations (1) and (2). BHI value for the bridge comes out to be 95.06 indicating that the bridge is in excellent condition.

The details of distress types, condition state number W_j, CS_j, CI_i for those bridge subcomponents which are not applicable for this field application are not shown in **Table 7.6** due to space constraint. For example, on inspection, it was found that the bridge does not have weep holes and pier protection works etc., accordingly these are not shown in **Table 7.6.**

Table 7.6 Application of BHI

Sl. No.	Bridge components	Distress Type	Condition State No.	W_j	CS_j	CI_i	BHI
C1.0	**Approaches**					75.65	95.06
C 1.1	Alignment	Nil	I	16	100		
C 1.2	Signages	Missing elements	II	5.8	75		
C 1.3	Embankment/ cutting	Nil	I	12.9	100		
C 1.4	Railing/crash barriers/guard stones/ parapet	Missing	V	15.2	0		
C 1.5	Approach slab	Nil	I	9.7	100		
C 1.6	Approach joint	Nil	I	9.9	100		
C 1.7	Side drains	Clogging	II	10.3	75		
C 1.8	Slope protection	Erosion	II	20.1	75		
C 2.0	**Substructure**					95.03	
C 2.1	Abutment	Nil	I	14.2	100		
C 2.2	Abutment cap	Nil	I	11.1	100		
C 2.3	Dirt wall	Nil	I	5.2	100		
C 2.4	Weep holes	NA	I	4.5	100		
C 2.5	Wing walls	Nil	I	7.1	100		
C 2.6	Abutment protection works	Nil	I	9.0	100		
C 2.7	Pier	Nil	I	21.8	100		
C 2.8	Pier cap	Exposed reinforcement	II	14.6	68.75		
		Corrosion	II				

		Spalling	II				
		Staining	III				
C 2.9	Pier protection works	NA		12.5	100		
C 3.0	**Waterway/channel**						
C 3.1	River/channel bed	Silting	II	4	62.5	98.50	
		Vegetation	III				
C 3.2	Guide bunds	Vegetation	II	13	100		
C 3.3	Spurs	NA		8.4	100		
C 3.4	Retaining wall	NA		15	100		
C 3.5	Toe walls	NA		7.6	100		
C 3.6	Floor/channel protection	NA		12	100		
C 3.7	Apron	NA		11.3	100		
C 3.8	Curtain/cutoff walls	NA		14.7	100		
C 3.9	Ground/rock anchors	NA		14	100		
C 4.0	**Foundations**						
C 4.1	Foundations (raft/open/pile/well)	Not visible		66	100	100	
C 4.2	Apron	Not visible		13.9	100		
C 4.3	Foundation protection	Not visible		20.1	100		
C 5.0	**Superstructure**						
C 5.1	Girders/Main beams	Nil	I	35	100	100	
C 5.2	Cross beams/ diaphragms	Nil	I	14.2	100		
C 5.3	Articulation	Nil	I	12.7	100		
C 5.4	Deck slab	Nil	I	15.1	100		
C 5.5	Cantilever slab	Nil	I	13.2	100		
C 5.6	Joints	NA		9.8	100		
C 6.0	**Appurtenances/Auxiliary works**						
C 6.1	Wearing surface	Rutting	II	7.9	75	89.77	
C 6.2	Footpaths	Nil	I	7.3	100		
C 6.3	Expansion joints	Clogging	II	17.8	75		
C 6.4	Restressing elements (anchorages etc.)	Nil	I	18.7	100		

C 6.5	Median	Nil	I	4.8	100		
C 6.6	Kerbs/cornices	Nil		4.6	100		
s	Light posts	Crushing/damaged	II	3.7	50		
C 6.8	Drainage spouts	Clogging	II	7.4	75		
C 6.9	Parapet/railing/ guard stones/crash barrier	Nil	I	11.9	100		
C 6.10	Waterproofing system	NA		7.6	100		
C 6.11	Painting system	NA		4.3	100		
C 6.12	Utilities	Nil	I	3.9	100		
C 7.0	**Bearings**						
C7.1	Bearings	Rusting	II	50	75	81.15	
C 7.2	Bearing seats/caps	Rusting	II	25.4	75		
C 7.3	Earthquake restraints	NA		24.6	100		

Since BHI value is more than 80 hence it is in excellent condition having Five Star rating. Since there are no components in critical Condition State that is V and needs very less consideration no urgency as far as maintenance and repairs is concerned.

7.7 Priority Factors

In reality Bridge Condition is not the sole criterion for deciding the priority of maintenance. Implementing agencies can develop variety of priority models taking into account the different factors as per their policy and requirement. One of the models taking into consideration of the factors enumerated in **Table 7.7** is proposed on the similar lines of BHI as mention below:

i) Categorization of Priority factors

ii) Relative Importance Priority factors

iii) Classification of Priority factors in accordance with their relative values

iv) Mathematical Model

v) Illustrative Example

7.8 Relative Importance of Priority Factors

The categorization of priority factors and their relative weights are given in **Table 7.7**

Table 7.7 Maintenance Priority Factors and their Relative Importance

$$MPI = \frac{\sum_{i=1}^{N} W_i \times FR_i}{\sum_{i=1}^{N} W_i} \quad (4)$$

$$FR_i = \frac{\sum_{j=1}^{n} W_j \times PR_j}{\sum_{j=1}^{n} W_j} \quad (5)$$

Bridge Geometry **4.38%**	**Maintenance Policy** **8.67%**	**Fund Utilization** **5.33%**	**Bridge Design Factors** **8.05%**	**Urgency of Maintenance** **22.22%**	**Bridge Importance** **18.58%**	**Bridge Condition** **29.68 %**	**Administrative Considerations** **3.09%**
F1.1 Length (16.27%) **F1.2** Carriage way width (10.67%) **F1.3** Waterway (42.85%) **F1.4** Clearances (30.21%)	**F2.1** Future planning considerations (5.78%) **F2.2** Safety to road users (30.73%) **F2.3** Maintenance policy (12.70%) **F2.4** Obsolescence of bridge (9.92%) **F2.5** Deterioration rate (40.87%)	**F3.1** Fund availability (15.15%) **F3.2** Maintenance cost (20.22%) **F3.3** Diversion cost (8.3%) **F3.4** Life cycle cost (24.63%) **F3.5** Optimal utilization of funds (32%)	**F4.1** Environment (10.48%) **F4.2** Load carrying capacity (30.41%) **F4.3** Age (15.31%) **F4.4** Seismic vulnerability (43.81%)	**F5.1**Public Demand (8.82%) **F5.2**Economic development of area (17.63%) **F5.3**Emergency (73.55%)	**F6.1**Strategic importance (34.47%) **F6.2**Location (11.35%) **F6.3** Category of road (10.97%) **F6.4** Traffic volume (43.21%)	--	--

7.9 Maintenance Priority Index Model

Following equations are proposed for the determination of Maintenance Priority Index (MPI) where Wi is the corresponding relative weights of main factors; N is the main factors = 1 to 8; FRi is the factor rating of each main factor; Wj is the corresponding relative weight of sub-factors; PRj is the priority ranking value of each factor based on its classification; n is the number of related sub-factors.

The weights generated using AHP analysis based on the relative ranking and the priority ranking values to be used are given in **Table 7.8.**

Table 7.8: Classification of Priority Ranking Values for Priority Factors

Sl. No.	Priority factor	Priority Ranking Values (PR_j)				
		0	**25**	**50**	**75**	**100**
1	Environment	Normal	Low intensity	Medium Intensity	High Intensity	Severe Intensity
2	Traffic Volume	<150CVD	150-450 CVD	450-1500 CVD	1500-4500 CVD	>4500 CVD
3	Seismic vulnerability	--	Zone II	Zone III	Zone IV	Zone V
4	Age	< 10 years	10-20 years	20-40 years	40-60 years	>60 years
5	Length of the bridge	--	<10 m	10-30 m	30-60	>60 m
6	Carriageway width	--	<3.75 m	3.75 to 7 m	7-14 m	>14 m
7	Waterway	--	< 10 m^2	10-100 m^2	100-500 m^2	>500 m^2
8	Location	Least significant	Moderately significant	Strongly significant	Very strongly significant	Extremely significant
9	Clearances	Adequate	--	--	--	Inadequate
10	Load carrying capacity	Adequate	--	--	--	Inadequate
11	Fund availability	--	80%	70%	60%	50%
12	Future planning	No	--	--	--	Yes
13	Maintenance cost	--	Extreme	Large	Moderate	Least
14	Deterioration rate	Least	Moderate	Strong	Very strong	Extreme
15	Optimal utilization of funds	No	--	--	--	Yes

16	Obsolescence of bridge	Useful	Least obsolete	Moderately obsolete	Large	Extreme
17	Public demand	No	Least	Moderate	Large	Extreme
18	Economic development of area	No	Least	Moderate	Large	Extreme
19	Maintenance policy	--	--	Preventive	--	Reactive
20	Life cycle cost (LCC)	No	--	--	--	Yes
21	Emergency	No	Least urgent	Moderate urgent	Urgent	Extremely urgent
22	Diversion cost	Extreme	Large	Moderate	Least	No
23	Bridge condition	Excellent	Good	Fair	Poor	Critical
24	Strategic Importance	No	Least	Moderate	Large	Extreme
25	Administrative considerations	No	Least	Moderate	Large	Extreme
26	Category of the road	Other District Roads	Major District Roads	State Highways	National Highways	Expressways
27	Safety of road users	No	Least important	Moderately important	Largely important	Extremely important

7.10 Illustrative Example

The two bridges in the same locality having the BHI value of bridges 1 and bridge 2 observed to be 75.69 and 85.66 respectively. These values of the BHI were used for the bridge condition as a priority factor.

For the remaining priority factors, data collected from the bridge authorities and given in **Table 7.9**

Table 7.9: Application of MPI

No.	Priority factors	Relative weights	Priority Rank Value classification		Priority Ranking Bridge 1	Priority Ranking Bridge 2
F 1	**Bridge Geometry**	**4.38**				
F 1.1	Length	16.27	<10 m	25	100	100
			10-30 m	50		
			30-60	75		
			>60 m	100		
F 1.2	Carriageway width	10.67	<3.75 m	25	75	75
			3.75 to 7 m	50		
			7-14 m	75		
			>14 m	100		
F 1.3	Waterway	42.85	< 10 m^2	25	75	75
			10-100 m^2	50		
			100-500 m^2	75		
			>500 m^2	100		
F 1.4	Clearances	30.21	Adequate	0	0	0
			Inadequate	100		
F 2	**Maintenance Policy**	**8.67**				
F 2.1	Future planning considerations	5.78	No	0	0	0
			Yes	100		
F 2.2	Safety to road users	30.73	No	0	25	25
			Least important	25		
			Moderately important	50		
			Largely	75		

			important			
			Extremely important	100		
F 2.3	Maintenance policy	12.70	Preventive	50	100	100
			Reactive	100		
F 2.3	Obsolescence of bridge	9.92	Useful	0	0	0
			Least obsolete	25		
			Moderately obsolete	50		
			Large	75		
			Extreme	100		
F 2.4	Deterioration rate	40.87	Least	0	50	25
			Moderate	25		
			Strong	50		
			Very strong	75		
			Extreme	100		
F 3	**Fund Utilization**	**5.33**				
F 3.1	Fund availability	15.15	80%	25	25	25
			70%	50		
			60%	75		
			50%	100		
F 3.2	Maintenance cost	20.22	Extreme	25	75	75
			Large	50		
			Moderate	75		
			Least	100		
F 3.3	Diversion cost	8.29	No	100	50	50
			Least	75		
			Moderate	50		

			Large	25		
			Extreme	0		
F 3.4	Life cycle cost	24.63	No	0	0	0
			Yes	100		
F 3.5	Optimal utilization of funds	31.69	No	0	0	0
			Yes	100		
F 4	**Bridge Design Factors**	**8.05**				
F 4.1	Environment	10.48	Normal	0	50	25
			Low intensity	25		
			Medium intensity	50		
			High intensity	75		
			Severe intensity	100		
F 4.2	Load carrying capacity	30.41	Adequate	0	100	0
			Inadequate	100		
F 4.3	Age	15.31	< 10 years	0	75	25
			10-20 years	25		
			20-40 years	50		
			40-60 years	75		
			>60 years	100		
C 4.4	Seismic vulnerability	43.81	Zone II	25	75	75
			Zone III	50		
			Zone IV	75		
			Zone V	100		
F 5	**Urgency of Maintenance**	**22.22**				
F 5.1	Public demand	8.82	No	0	100	100

			Least	25		
			Moderate	50		
			Large	75		
			Extreme	100		
F 5.2	Economic development of area	17.63	No	0	50	50
			Least	25		
			Moderate	50		
			Large	75		
			Extreme	100		
F 5.3	Emergency	73.55	No	0	0	0
			Least urgent	25		
			Moderate urgent	50		
			Urgent	75		
			Extremely urgent	100		
F 6	**Bridge Importance**	**18.58**				
F 6.1	Strategic importance	34.47	No	0	50	50
			Least	25		
			Moderate	50		
			Large	75		
			Extreme	100		
F 6.2	Location	11.35	Least significant	0	50	50
			Moderately significant	25		
			Strongly significant	50		
			Very strongly	75		
			significant			
			Extremely	100		

			significant			
F 6.3	Category of road	10.97	Other District Roads	0	25	25
			Major District Roads	25		
			State Highways	50		
			National Highways	75		
			Expressways	100		
F 6.4	Traffic volume	43.21	<150CVD (CVD: Commercial Vehicle per Day)	0	75	75
			150-450 CVD	25		
			450-1500 CVD	50		
			1500-4500 CVD	75		
			>4500 CVD	100		
F 7.0	**Bridge Condition**	**29.68**	Excellent	0	50	25
			Good	25		
			Fair	50		
			Poor	75		
			Critical	100		
F 8.0	**Administrative Considerations**	**3.09**	No	0	50	50
			Least	25		
			Moderate	50		
			Large	75		
			Extreme	100		

The MPI value of bridge 1 and bridge 2 are computed using equation (4) and (5) and found to be 44.89 and 33.21 respectively. It may be noticed that both of the bridges being located in the same locality, priority values for most of the factors are same. The difference in MPI value is mainly due to the difference in their health condition (BHI value), age and load carrying capacity. The MPI values can be used for deciding the priority at network level (Center) or regional level (States/UTs).

The MPI may be simplified by reduction in number of priority factors. The only requirement is that total weights shall be equal to 100. The MPI may be modified or number of factors reduced if so needed.

7.11 Optimization Techniques

In order to optimize the resources once the priority has been decided at local levels various optimization techniques/algorithms may be utilized. For example objective may be to minimize the cost of maintenance among the various maintenance options available. Another could be minimize the risk or maximize the service life. There may be single objective or multiple objectives depending on the policy, necessity and capability to develop such models.

CHAPTER 8

MAINTENANCE TECHNIQUES

8.1 Maintenance

Maintenance activity meant either to prevent or rectify the effects of deterioration. This may include partly or wholly restore a specific component back to the original condition anticipated in the design. Maintenance is usually preferred and done periodically.

It comprises of any activity and work including inspection necessary to enable a structure to continue to fulfill the intended function or to sustain its original or required form and appearance. It excludes any work leading to improvement of the structure whether by strengthening, widening or by vertical realignment of the road surface, repairs of any damage caused by exceptional causes like landslides, earthquakes, cyclones, fire, etc. The maintenance operation starts with the opening of the bridge to traffic.

8.1.1 Maintenance Objectives

The maintenance objectives aim at maintenance and operations of road/highway system in such a manner as to:

i) Provide comfort, convenience and safety to users.

ii) Improve operational capability and efficiency of the structure.

iii) Prevent deterioration and enhance life of the structure.

iv) Avoid the accumulation/augmentation of minor defects which manifest in the form of major defects at a later date.

v) Reduce the operation cost and travel time.

vi) Secure the investment in bridges and appurtenances.

vii) Preserve aesthetics and compatibility of the system with environment.

viii) Ensure necessary resources are utilized economically.

ix) Restore normal traffic operations efficiently in the event of unsafe conditions, lane closures, diversions, natural calamities, accidents, etc., by adopting suitable safety measures.

x) Prolong the life of assets through timely repairs.

xi) Maintain serviceability levels of assets during their service life; and

xii) Enhance performance levels through engineering improvements for meeting reasonable demands of road users.

8.2 Types of Maintenance

Maintenance Operations can be of two types, viz. ordinary/routine maintenance operations and specialized maintenance operations. The operations of repetitive or periodical type are in general technically rather simple and are classified as ordinary maintenance operations.

The specialized maintenance operations are those which are unpredictable regarding their necessity and are relatively more complex. However, it must be admitted that the line separating them is rather a fine one. They may be preventive as well as reactive or both. They may be carried out as planned or unplanned activities.

Maintenance addresses the requirement related to aesthetics, functionality, post inspection corrective measures and general up keep of the bridge.

8.2.1 Ordinary/Routine Maintenance

These are the works needed to preserve the intended serviceability, load carrying capacity of the bridge and ensure continued safety of both structures & road users. The maintenance operations generally begin with the opening of the bridge to traffic provided it is completed in schedule time and shall include the following or similar activities.

- Clearing, grubbing, removing bushes & plants, etc.
- Simple cleaning by mechanical means or by manual (of carriageways, foot-paths verges, joints, drains, gulleys, gutters etc.)
- Removal of foreign material such as trash or parasitic vegetation and similar operations.
- Substitution of deteriorated elements by removal and replacement operations (e.g. safety barriers)
- Small restorations, re-pointing of masonry and brickwork, replacement of missing stones, sealing and repairs with cement or resin mortars.
- Localised repairs to pavements and waterproofing, using bituminous materials, fillers in expansion joints.
- Clearing of ventholes in superstructure.
- Localised painting operations to protect against corrosion.
- Renewal of protective treatments on timber.
- Lubrication and greasing operations.

8.2.2 Specialized Maintenance

Specialized Maintenance includes restoration of concrete (reinforced or otherwise) structural parts, which can be carried out with simple or special techniques using cement mortars, synthetic mortars, etc. as mentioned below:

- Increase resistance of concrete in case of physical or chemical attack.
- Restoration of brick or masonry structure.
- Protection of timber, concrete, steel or masonry from degrading actions by frost, salts or the atmosphere by means of painting (protective films), impregnation, disinfestations etc.
- Injection of cement grout or thermosetting resin into cracks in brick, stone, reinforced or pre-stressed concrete structure.
- Injection of cement grout or synthetic resin (with or without additives) into sheaths containing pre-stressing tendons.
- Maintenance for reduction or prevention of harmful agents like water, other liquids, vapour, gas, chemicals and biological agents.
- To control moisture content in the body of concrete by surface coating, over cladding, hydrophobic impregnation or by electro chemical treatment.
- To preserve passivity by increasing cover to bars, control anodic areas by painting reinforcement with coatings, barrier coatings by applying inhibitors to the concrete.
- Maintenance of bolts or welding of metal structures; cleaning, greasing and substitution of wearing parts of same.
- To check looseness of rivets and HSFG bolts and restore to desired level and maintain.
- To repair and maintain deficient steel members because of corrosion, cracks, buckling and bending etc.
- To repair heavy corrosion in the contact of bearings with steel girders in steel bridges.
- To check, repair, replace tilting of bearings its misalignment or assembly.
- Anti-corrosion protection of metal structures/concrete structures entailing complete stripping and repainting of part or all of the surface with environmentally compatible paint.
- Repair or reconstruction of drainage system (gullies, channels, collector and discharge pipes etc.)
- Repair or reconstruction (partial or total) of expansion joints, depending on their types.
- Repair or reconstruction of pavements or waterproofing of deck.
- Maintenance of bearings by means of different operations depending on the type (repainting, graphiting etc.); setting of same also by raising decks.
- Replacement of rollers of metallic bearings; setting of same, if required, by raising decks or deck including girders.
- Maintenance of seismic stoppers by compatible means.

- Repair of crushed or cracked bed blocks under bearings with the same methodology as in case of change of bearings.
- Reclamation operations of river and sea beds to protect foundation structures.
- Repairs for damages to guide bunds, aprons, cutoffs for open/raft foundations and protective works around abutment and approach embankments.
- Making up settlement on bridge approaches.
- Strengthening or replacement of distressed, or damaged replaceable elements.
- Restoration of settlement on bridge approaches.
- Replacement of any structural members (mainly for timber or steel structure).
- Removal of encroachments.

A comprehensive record of all encroachments including their locations, extent of encroachment and unauthorized accesses to the bridge should be maintained and a plan should be proposed to remove these encroachments with the help of local civil authority's assistance.

The above lists are not exhaustive, but only indicative will have to be updated and similar activities shall be included.

8.3 Minor Repairs and Rehabilitation

These activities also meet the above definition of maintenance but are larger in scope and cost than maintenance. Rehabilitation operations aim at restoring the bridge to the original service level which has now been reduced. In some cases this covers improving the bridge to the service level, which was intended, but which has never been attained, because of the deficiencies in the original design or construction.

Minor Repairs & Rehabilitation generally include the following type of works:

- Upkeep of road pavements and side shoulders (wearing coat and approaches).
- Upkeep of roadside drainage system.
- Upkeep of culverts and bridges and earth retaining structures, wing walls, reinforced earth walls and parapets, this would inter-alia cover the replacement.
- Keeping the sign boards, kilometer and hectometer stones, pavement markings, delineators including other traffic aids and furniture in good shape and condition.
- Maintenance of street lighting and telecom system.
- Maintenance of arboriculture in approaches and below on plains.

- Taking pro-active measures in advance of monsoon season for maintenance of vulnerable items like road surfaces, joint sealant in cement concrete pavements, shoulders, embankments, drains, culverts, etc.
- Taking post monsoon maintenance of shoulders, embankments, drain, culverts, protective works, scour holes, bridges in hilly areas prone to effects of landslide, bridges in severe exposure conditions and also restoration of pointing of masonry works and placement of missing stones.
- Maintenance of other project facilities like pedestrian facilities, cattle crossings, medical aid posts, traffic aid posts, etc.
- Maintenance of access/approach roads and junctions.
- White/color washing painting of parapets, kerb stones, km stone, railing, structures, etc.
- Painting and numbering of approach road 'side trees, culverts and other structures.
- Repair of road sign board, crash barriers, etc.
- Repair of overhead and other light facility and telecom facilities.

8.4 Maintenance Strategies

A good maintenance policy should be one of the important aims of any highway department as it is the responsibility of the highway authority to maintain the network to specified performance standards. It is needed to have preventive maintenance policy rather than reactive.

The maintenance strategies consistent with the objectives and policies besides achieving improved performance, enhanced safety and better economy in traffic operations would inter-alia cover the following salient features:

- Formulating a clear statement on objectives, policies and procedures for execution of various types of maintenance activities.
- Identifying a defined network of all infrastructure, meeting the required standards and reasonable demands of highway users.
- Adopting a systematic approach in decision making within a consistent framework of policies, standards and procedures.
- Using a uniform criteria for assessing the maintenance and resource requirements.
- Assisting in the effective allocation of resources.
- Reviewing regularly the maintenance policies, procedures and monitoring the effectiveness of maintenance programs.

- Selecting an approach which gives best value for money and asset management philosophy for highway maintenance.

It is necessary for the road authorities to issue detailed instruction for classification of their bridges according to size, span length, type of structure, condition of exposure, materials of construction etc. and assign the responsibilities for their inspection (routine, principal and special) at various levels depending on the importance, vulnerability and complexity of the structure, along with periodicities of such inspections as per these guidelines.

Steps should be taken to procure necessary means of accesses for bridge inspections, including at least one mobile bridge inspection unit in each state. Where so justified by the work load, separate units may be set up for inspection; particularly for the principal and special ones for important bridges, creating data base and inventorisation.

Equally important is the task of adequate monitoring to ensure that the necessary inspection as prescribed are being actually carried out properly and necessary follow up actions arising out of these inspections are initiated and implemented. It is desirable that one senior engineer for the whole organization in the road authority should be exclusively appointed for this purpose.

It is recommended that in following the guidelines, the road authorities should carry out all the inspections prescribed here for all bridges to assess their conditions. While it might be relatively easier to compile a bridge inventory on basic data from record drawing (which may also not be readily available in many cases), considerable efforts will be required to compile the bridge data files after carrying out inspections.

Inspections should also be carried out particularly in respect of bridges known to have some history of distress or those located in aggressive environments. All new bridges should be inspected soon after their construction. This will help in noticing the defects within the Defect Liability Period (DLP) of the contract and to serve as a bench mark for subsequent inspections.

There is a need to either develop or promote bridge maintenance and bridge rehabilitation agencies. Specialized equipment required for bridge rehabilitation and strengthening should be procured by the concerned authorities and preferably some core units should be set up to carry out such works departmentally. For any particular bridge where problems are of complex nature; the consultants should be employed depending on the nature and magnitude of the work.

However, departmental units should be strengthened to oversee the progress, verifying the details, analyzing the data etc. submitted by the consultants. In some cases, it will be necessary to supplement the Departmental efforts by consultants who would be in a position to command the required man-power as well as expertise to cope up with the increased work load on short term basis. It might be necessary to encourage and develop consultancy firms for bridge inventorisation and rehabilitation in addition to the agencies for carrying out the actual work of rehabilitation in addition to the agencies for carrying out the actual work of rehabilitation and maintenance of bridges.

It is preferable to create a separate bridge design and maintenance units/zones exclusively by each State/UTs or implementing agencies.

Investigation of the distress, their causes and finding remedial measures require special expertise. Only the experienced and competent bridge engineers are able to diagnose the distress and suggest most appropriate methods of repairs. More often than not, the engineer directly in charge of bridge structures may not have the expertise to deal with major distress in a bridge structure. The major distress in a bridge could be a multi-disciplinary problem, involving structural defects, corrosion, deficiencies in hydraulic design, construction issues, soil related & foundation defects etc. for with which consultation with experts from relevant fields both within the department as well as from outside may become necessary and extremely useful, especially for important and vital bridge structures.

The management of bridges has not been receiving much attention as it should be, from both the financial and engineering inputs. As already mentioned, the funds for repairs and maintenance are normally allocated in lump sum amounts for repairs and maintenance of roads including bridges. In order to focus attention of both the Government and Engineers, it is recommended that there should be a separate budget item for inspection, repairs, rehabilitation and strengthening of bridges.

A bridge maintenance programmer along with cost estimates should, therefore, be prepared every year and provision of funds to the extent of estimated expenditure should be included in the budget.

Maintenance of structure has to be handled by experienced engineers and trained technicians. Training of these personnel is essential. The training institutes should prepare appropriate modules exclusively for bridge maintenance and rehabilitation. All the consultants shall engage only trained bridge inspectors and engineers for the purpose.

The concerned engineer will find it difficult to keep his knowledge upbreast on the testing techniques, materials and maintenance procedures. So, in service training courses shall be planned by specialists in the field. This is most highly recommended and shall be held frequently. Similarly, practical courses are desirable for all maintenance teams working on site to adequately train them. Also the teams shall be insured against risks and should be trained on safety precautions needed in maintenance works. This should include the use of protective clothing, helmet, breathing mask, eye shields and safety belts, while working on elevated structures including scaffolding, in confined places and over water.

A separate manual for training of personnel engaged in bridge inspection and maintenance needs to be compiled and made available to organizations having a large number of bridges under their control. The manual should contain detailed instructions for the personnel in charge of inspections at all levels, their qualifications, handling equipment and tools, observations of necessary safety precautions, filling in of inventory forms and inspection forms, use of camera for taking appropriate photographs etc.

The instruction must be in simple language preferably in regional languages and formats like Do's and Don'ts and should be illustrated with appropriate sketches and photographs to guide the bridge inspection personnel in their task.

Apart from the technical aspects, the engineers and the authorities should be aware of the importance of non-technical aspects of management of distressed bridges, such as public safety, public relations, legal issues, etc. These aspects need to be handled tactfully and competently by the top level of management depending on the importance of the bridge. As soon as distress or damage to the bridge comes to light and if the traffic is either to be restricted or diverted or stopped completely, it is essential to keep the public informed of all the facts regarding the bridge through suitable media. A standard hand-out should be kept ready and should be distributed, updating it from time to time. For vital bridges and bridges of strategic importance, as soon as distress is noticed, a contingency plan should be worked out and kept ready for implementation, the moment it becomes necessary. The contingency plan has to be prepared in consultation with all concerned departments. Merely investigating the cause of distress and carrying out remedial measures and restoring the traffic may not be enough. One must also draw lessons from such occurrences for improvements in future structures so as to minimize chances of recurrence. The lessons learnt should be made known to other engineers also.

For improved techniques to carry out maintenance and repairs, it is necessary to meet the criteria of practicability like:

i) Techniques must be robust and should not be unduly sensitive to workmanship or defects.

ii) Techniques must be resistant to environmental conditions.

iii) Techniques should preferably involve proven technology and new ideas should be introduced with due care and attention.

iv) It shall not be proprietary.

For maintenance policy and strategies, relevant clauses in **Chapter-2** of SP:40 may also be referred to.

8.5 Maintenance Research and Development Needs

8.5.1 Requirements

A great deal of research is going on in India and other parts of the world on structural aspects. These deal with concrete bridge deck, their waterproofing and corrosion protection of reinforcement and damaged concrete repairs. Reports to pre-stressed concrete members, strengthening of old bridges metal protection, etc.

It is somewhat difficult to clearly separate out research consideration that pertains only to bridge maintenance. However, the broad requirements of research and development in maintenance can be summarized as follows:

i) To investigate the effectiveness of applied method of maintenance.

ii) To develop performance/assessment criteria in accordance with the condition states for NDT methods

iii) To develop performance criteria for evaluation of different maintenance strategies.

iv) Developing improved materials and techniques for bridge maintenance and

v) The study of economics of maintenance of bridges of various ages and types.

8.5.2 Future Research

It will be observed that there is a considerable gap between the present bridges maintenance practices and the desired maintenance practices & requirements. To close the gap, a great deal of knowledge of all relevant aspects of bridges maintenance is yet to be gained and disseminated. Carefully planned and executed research has to be planned. The research could be broadly classified into (a) physical maintenance research and (b) non-physical maintenance research dealing with materials, techniques, costs, practices and policies.

8.5.2.1 Research Needs for Physical Maintenance

This may include but not limited to the following:

i) Repairs of concrete like crack repairs, development of suitable material & method, techniques to repair deteriorated concrete, protective coating etc.

ii) Corrosion protection of RCC steel as well as high tensile steel in pre-stressed concrete.

iii) Development of expansion joints and bearing with improved materials, techniques and serviceability.

iv) Grouting technology of pre-stressing cables including techniques for examining the quality of grout in embedded cables.

v) Fatigue crack repairs in steel bridges.

vi) Use of polymer modified concrete, latex modified concrete, self compacting concrete and fibre concrete in replacement of removed concrete.

vii) Development of instrumentation and computer based multichannel data acquisition system.

viii) Development of a special standard testing vehicle where, it is possible to gradually increase the axle loads conforming to national classification such as 40R, 70R and other loading as per IRC:6

ix) Addition of steel reinforcement in the shape of bars, plates, plates etc., to the distressed elements. Successful bonding to the parent structure requires development of appropriate gluing materials as well as techniques of execution.

x) Measurement of pre-stressing forces in embedded tendons.

xi) Strengthening by external pre-stressing.

xii) Non-destructive method of detecting corrosion in pre-stressing steel and to measure rate of corrosion of steel in concrete.

xiii) Underwater bridge inspection and repairs.

xiv) Techniques for controlled and rapid removal of concrete without damage to concrete and steel left in place.

xv) Assessment of residual pre-stress.

xvi) Improvements in metallurgy of steel reinforcement and for pre-stressing steel to improve corrosion resistance.

8.5.2.2. The Research Need of Non-physical Aspects of Maintenance

This may include but not limited to the following:

i) Long term behvaiour studies for methodical evaluation of effectiveness of various maintenance & repair techniques.

ii) Assessment of condition based on BHI/Bridge Condition Rating.

iii) Maintenance strategies and their effectiveness.

iv) Cost implications and decision making.

v) New materials and techniques.

vi) Proper maintenance accounting.

The above lists are not exhaustive with time more areas for research can be opened up.

CHAPTER 9
RESEARCH AREAS & REFERENCES

9.1 Research Areas

Following research areas pertaining to BMS are suggested which may be helpful in further improvement of the guidelines.

1. Environmental Life Cycle Assessment of Bridges.
2. Rehabilitation and life extension techniques for reinforced concrete, pre-stressed concrete and steel bridges in corrosive atmosphere.
3. Identification of defects in grouting of pre-stressing cables in bridges.
4. Development of innovative non-destructive techniques for determination of in-situ strength and permeability of concrete.
5. Development of technologies, systems and equipment for accelerated bridge construction.
6. Development of innovative materials and techniques to assess and improve durability of bridges in aggressive environment.
7. Manufacture of High Damping Rubber Bearings and other types of bearings for seismic isolation of Bridge superstructures.
8. Use of FRP (Fibre Reinforced Polymer) composites in bridges: manufacturing process, improvement of ductility and design methodologies.
9. Long life, Low Maintenance Structures.
10. Development of Assessment methodology for Bridge based on GPS software.
11. Establish correlation between various distress types and IRI (International Roughness Index)/Deflection roads and bridges.
12. Development of deterioration models for various bridge components.
13. Rationalization of live loads for bridges for NHs & other roads.
14. Handbooks for construction, maintenance & Inspection for bridges.
15. Evaluating the structures with their current health-state assessment data.
16. Development of Analytical Model for Efficient Utilization of Funds for Bridges (Maintenance as well as Development).
17. Development of Expert System for prioritization of Bridges.
18. Development of Expert System for distress diagnosis of Bridges.
19. Development of Risk Assessment Index/Models based on Safety Audit for Bridges.
20. Study the Effect of Environmental Aspects (Temperature/Humidity/Wind/Climatic Zones and Seismic Zone) in Deterioration Models for Bridges.
21. Assessment of Remaining Life on the basis of Visual Inspection and NDT Results for Bridges.

22. Assessment of Socio-Economic Impact of Distressed Bridges.
23. Priority Tools for Ranking and Fund Utilization for Bridges.
24. Assessment of Maintenance Requirement of Bridges.
25. Environmental Impact Assessment of Distressed Bridges.
26. Risk Analysis Techniques for Bridges.
27. Life Cycle Cost Analysis of Maintenance (Rehabilitation) and Replacement.
28. Structural Health Monitoring Techniques for Bridges.
29. Advancement in NDT Techniques for Bridges.
30. Optimization Techniques for Bridge Maintenance Priorities.
31. Condition Analysis of existing Masonry Bridges.
32. Preservation Techniques of existing Masonry (Stone, Brick & Concrete) Bridges.
33. Analysis and design of Masonry and Concrete Wing Walls.
34. Corrosion Preventive Techniques.
35. Economic Viability of Stainless Steel Reinforcement.
36. FRP/GRP in Concrete.
37. New Trends in Bridge Bearings (Types, Materials, Manufacturing, Quality Control, Acceptance Criteria, Testing).
38. Defects in Bearings-Diagnosis and Remedial Measures.
39. New Trends in Types of Bridge Superstructures.
40. New Construction Methodologies for Bridge Superstructures.
41. Joints in Bridge Concrete Elements-Types, Materials, Applications, Defects, Quality etc.
42. Review of Surface and Subsurface Geotechnical Investigations for Bridges.
43. Review of River Training and Protection Works.
44. Expansion Joints-Types, Materials, Construction, Quality, Defects, Remedial Measures.
45. Railing and Crash Barriers-Types, Materials, Construction, Quality, Defects, Remedial Measures.
46. New Trends of Repairs of Structures (Concrete, Masonry, Steel etc.).
47. Modern Maintenance Techniques for Bridges.

9.2 References

The lists of primary references used for the revision of document are as below:

1 IRC:5 Standard Specifications and Code of Practice for Road Bridges, Section I – General Features of Design

2 IRC:6 Standard Specifications and Code of Practice for Road Bridges, Section II – Loads and Stresses

3 IRC:78 Standard Specifications and Code of Practice for Road Bridges, Section VII – Foundations and Substructure

4 IRC:83 (Part I) Standard Specifications and Code of Practice for Road Bridges, Section IX – Bearings, Part I: Metallic Bearings

5 IRC:83 (Part II) Standard Specifications and Code of Practice for Road Bridges, Section IX – Bearings, Part II: Elastomeric Bearings

6 IRC:83 (Part III) Standard Specifications and Code of Practice for Road Bridges, Section IX – Bearings, Part III: POT, POT-CUMPTFE, PIN and Metallic Guide Bearings

7 IRC:83 (Part IV) Standard Specifications and Code of Practice for Road Bridges, Section IX – Bearings, Part IV: Spherical & Cylindrical Bearings

8 IRC:89 Guidelines for Design and Construction of River Training & Control Works for Road Bridges

9 IRC:SP:18 Manual for Highway Bridge Maintenance Inspection

10 IRC:SP:35 Guidelines for Inspection and Maintenance of Bridges

11 IRC:SP:37 Guidelines for Load Carrying Capacity of Bridges

12 IRC:SP:40 Guidelines on Techniques for Strengthening and Rehabilitation of Concrete Bridges

13 IRC:SP:52 Bridge Inspector's Reference Manual

14 IRC:SP:54 Project Preparation Manual for Bridges

15 IRC:SP:56Guidelines for Steel Pedestrian Bridges

16 IRC:SP:69 Guidelines & Specifications for Expansion Joints

17 IRC:SP:74 Guidelines for Repair and Rehabilitation of Steel Bridges

18 IRC:SP:80 Guidelines for Corrosion Prevention, Monitoring and Remedial Measures for Concrete Bridge Structures

19 Bridge Inspector's Reference Manual, US Department of Transportation.

20 Wakchaure Sanjay Sampat., Development of Bridge Health Index and Framework for Maintenance Planning, PhD Thesis, Department of Civil Engineering, Indian Institute of Technology, Delhi, India, 2011.

21 Wakchaure S.S., Vishnu Jayan and Jha K.N., Maintenance Priority Index for concrete bridges, *Indian Concrete Journal*, 88(3), 2013, pp. 20-28.

22 Dr. Sanjay Wakchaure , Vishnu Jayan and Dr. Kumar Neeraj Jha (2013). "Factors affecting Priority of Maintenance of Bridges, *Indian Concrete Journal*, 87(2), 37-45.

23 Daniel Justus, Sanjay S. Wakchaure and Kumar Neeraj Jha (2016), Prioritizing concrete bridges for maintenance using reliability index based on visual inspection, Indian Concrete Journal, 90(2), 42-53.

9.3 Acknowledgement

Number of photographs has been used in the preparation of this document which are available on the internet and documents which are acknowledged herewith without giving references to everyone.

APPENDIX-I

PROFORMA FOR INVENTORY OF BRIDGES

Sl. No.	ITEM	PARTICULARS
Administrative/General Data		
1	Name of State/UT	
2	Name of District	
3	Nearest City/Town/Village	
4	Name of the Circle	
5	Name of the Region	
6	Name of the Division/PIU	
7	Name of the Sub-Division	
8	Name of the Section/Link No.	
9	Location of bridge (chainage) km	
10	Name of bridge	
11	Name of river	
12	Number of bridge (if any)	
13	Road Type	Expressways (Urban/Rural), Highways (National/ Urban/Stat), Major Roads (District/Urban) Other Roads (District/Urban), VR, Galli roads etc.
14	Name of the Road	
15	Number of Road	Popular/Official Name

16	Latitude	
17	Longitude	
18	Altitude	
19	Name of the Agency /Custodian	
20	Year of Inventory	
21	Whether Pre-monsoon /Post-Monsoon	
22	Date of Inspection	NHAI/NHIDCL/PWD/BRO
23	Year of Construction (Start)	
24	Year of Completion	
25	Date of Opening to the Traffic	
26	Name of Builder Contractor	
27	Name of Supervision Consultant(AE/IE)	
28	Date of latest improvement / rehabilitation	
29	Specific comments, if any	

Structural Data (Shall be as per components)		
1	Function/Type of crossing Facility Carried by the Bridge	Road/Railway Crossings/ROBs/RUBs/VUP/ Intersections/Grade Separators/Flyovers/ Aqueduct/ Viaduct/Pipeline/River/Stream, FOB, Underpasses, Subways, Overpasses Canal, Sea/Creeks, Lakes, Reservoirs, Back water
2	Type of Bridge	Major / Minor
3	Whether Permanent/Temporary?	
4	Type of Underpass	Vehicular/Cattle/Pedestrian/Any other
5	Whether the Bridge is in Grade?	
6	Whether right angled/Skew bridge?	
7	Skew Angle in degree	If Curve then Radius of Curve, Super elevation may be added
8	Structural Configuration	Simply Supported, Continuous, Continuous Overhead, Balanced Cantilever, Suspension, Cable Stayed, Extra dosed, Arch, Slab, Integral, Cable Supported etc.
9	Type of Foundation	Open /Pile /Well and their types
10	Foundation Material	CC/Masonry/Timber/ FRC/FRP etc.
11	Depth of foundation (measured from bottom of substructure)	
12	Maximum Depth of Foundation in m	
13	Type of Substructure	Abutment/Pier

14	Pier Material	Timber/RCC/PSC/Steel/Stone masonry/Brick Masonry/Composite etc.
15	Pier Type	Solid/hollow/Circular/Oval/ (Circular, Rectangular Plate Type etc.)
16	Dimension of pier	
17	Depth of pier	
18	Dimension of abutment	
19	Abutment Type	Solid/Hollow/Circular/Semi-circular, Oval/ (Solid Type, Spill through type, Counter Fort, Buttressed
20	Abutment Cap	
21	Abutment Cap material	
22	Depth of Abutment	
23	Abutment Material	CC/RCC/Masonry
24	Type and Length of Retaining Wall / Reinforced Earth Wall/ Wing Wall/Dirt Wall	
25	Pier Cap	Solid/hollow/Circular/Oval
26	Pier Cap Material	CC/RCC/Masonry
27	Protection Works for Abutment & Pier	
28	Type of Superstructure	Slab, Voided Slab, T-Beam & Slab, Girder & Slab, Box Girder, Arch, Rigid Frame, Suspension, Cable Stayed, Extra dosed, Single/Multi Cell Box, Truss etc.
29	Depth of Superstructure	(Please capture overall depth as well as depth of Girder)

30	Type of carriageway	Single/Intermediate/Double/Multilane/ Divided etc.
31	Wearing coarse	Concrete/Bituminous
32	Type of Bearings	Sliding Plate/Rocker & Roller/Elastomeric/Paper/Concrete/ Metallic
33	Type of Expansion Joint	
34	Median Type	Raised, Depressed & Flushed
35	Median Width in m	
36	Shoulder Type	
37	Shoulder width in m	
38	Foot Path(LHS/RHS/Both)	
39	Footpath Type	
40	Kerb Type	
41	Kerb width in m	
42	Utilities Carried by Structure/Service ducts	Water/Sewer/Electrical/ Telephone/gas/ OFC/Oil
43	Guard Rail/Parapet Type	Steel, Concrete, Closed/Open etc.
44	Road Level	
45	Approach Roadway Width Including Shoulder	
46	Approach Shoulder Width	
47	Height of Approach Embankment in m	
48	Depth of Approach cutting in m	

49	Approach embankments	
50	Invert / aprons	
51	Fenders	
52	Retaining wall/ revetment	
53	Drainage system	Weep holes, Drainage Spout, Pipes etc.
54	Waterproofing	
55	Specific comments, if any	
Geometric Data		
1	Total length of bridge in "m"	Culvert, Minor, Major, Long Span Bridges
2	Total number of spans	
3	Effective Span Length in m	If needed C/C of joints may be taken
4	Waterway /Clear Span in m	
5	Width of carriageway in m	(between inner to inner edge of kerbs/crash barrier)
6	Width of footpath in m	(Please also mention whether the footpath is raised and whether it is provided on both sides or only on one side)
7	Overall width of deck in m	(from outer to outer)
8	Overall length	
9	Overall width	
10	Number of lanes (2/4/6...)	
11	Width of lanes	
12	Number of beams	(to be picked up for each type of spans)
13	Depth of main beams	

14	Width of main beams	
15	Number of transverse beams	
16	Depth of transverse beams	
17	Width of transverse beams	
18	Depth of concrete slab	
19	Centre to centre of bearings	
20	Span of masonry arch	
21	The rise of arch at the crown	
22	The rise of arch barrel at the quarter points	
23	The thickness of the arch barrel adjacent to the keystone	
24	The average depth of arch fill between road surface and arch barrel	
25	Height of parapet	
26	Height of columns piers	
27	Thickness of wearing course	
28	High Level or Submersible	
29	Whether Navigable?	
30	Whether located in back waters/chemical zone	Lakes/Reservoirs/Streams/Rivers/Canals
31	Whether Marshy/Protected	
32	Drainage Pattern	

33	Length under Submergence in km	
34	Length under Water logging in km	
35	Design High Flood Level (HFL)	
36	Abnormal Flood Level	
37	Low Water Level	
38	Ground Level	
39	Height of slab/superstructure in mm	
40	Maximum height between soffit Superstructure & river bed in m	
41	Free Board in m	
42	Average Rainfall in mm for each month	
43	Design Velocity m/s	
44	Design Discharge in Cumecs	
45	High Tide Level	
46	Low Tide Level	
47	Design Scour Level at Pier	
48	Design Scour Level at Abutment	
49	Specific comments, if any	

Traffic Data		
1	Traffic Volume (Through/Crossing)	PCU/CVD
2	Suspension of Traffic if any	
3	Duration of Suspension of Traffic	
4	Documentation of traffic data	
5	Brief description of accident classification e.g. Fatal, Grievous Injury, etc.	
6	Brief description of accident nature e.g. Overturning, Head on collision, etc.	
7	Probable reasons for accidents (Engineering, Driver etc.)	
8	Average Daily Traffic (ADT)	
9	Year of ADT	
10	Detour/alternate route Length	
11	Vertical Clearance in m	
12	Horizontal Clearance in m	
13	Access gantry	
14	Walkways / ladders	
15	Specific comments, if any	
Loading Data		
1	Pay load to be carried over the bridge. (GVW)	
2	Type of HT arrangement to be considered.	

3	Design Load Class	
4	Specific comments, if any	
Land Data		
1	Type of Terrain	Hilly/Mountainous/Plain/Meandering
2	ROW in m	
3	Land Use	Whether agriculture/Industrial/Urban/Restricted/Forest/ Wild life/Sanctuaries/Any other
4	Year of holding/transfer	
5	Whether Forest/Wild Life Sanctuaries/National Parks/ Industrial parks/Markets/ Missing Links/ Any other	
6	Whether Marshy/Protected	
7	Area in Ha.	
8	Type of Soil	Soft / Granular / Sandy / BC / Moorum /Clay /Silty / Sandy / Any other
9	Founding Strata	Alluvial, Moorum, Rock
10	Bearing capacity of soil	
11	Specific comments, if any	
Environmental Data		
1	Name of the meteorological station assigned by Indian meteorological department	
2	Temperature (Daily/Monthly/Average	Air/Water/Temperature/Humidity/Noise
3	Humidity	

4	Air Quality	
5	Snow fall duration/Thickness	
6	Earthquake/Seismic Zone	
7	Climatic Zone	
8	Whether subjected to contaminated water?	
9	Whether subjected to harmful chemicals & gases?	
10	Specific comments, if any	
Contact Details		
1	**(HQ/RO/Agencies/Police/Any other**	
Any other information / comments		

APPENDIX-II

PROFORMA FOR INVENTORY OF CULVERTS

Sl. No.	ITEM	PARTICULARS
Administrative/General Data		
1	Name of State/UT	
2	Name of District	
3	Nearest Town/Village	
4	Name of the Circle	
5	Name of the Region	
6	Name of the Division/PIU	
7	Name of the Sub-Division	
8	Name of the Section/Link No.	
9	Location of culvert (chainage) in km	
10	Sl. Number of culvert (if any)	
11	Feature crossed	
12	Road Type	
13	Name of the Road	
14	Number of Road	Popular/Official Name
15	Name of the Agency / Custodian	

16	Year of Inventory	
17	Whether Pre-monsoon /Post-Monsoon	
18	Date of Inspection	NHAI/NHIDCL/PWD/BRO
19	Year of Construction (Start)	
20	Year of Completion	
21	Name of Builder contractor	
22	Date of latest improvement / rehabilitation	
23	Specific comments, if any	
Structural Data (Shall be as per components)		
1	Type of culvert	RCC pipe / RCC slab on masonry/ or cc abutment/ RCC box / Arch (brick, RCC, precast) / Cut stone slab / Stone masonry scupper/ Vented causeway / Submersible bridge
2	Single cell / multiple cell	
3	Whether the culvert is in Grade?	
4	Whether right angled/Skew culvert	
5	Skew angle in degree	
6	Whether cut off wall is present	
7	Maximum Depth of Foundation in m	

8	Abutment height	
9	Abutment Type	Solid/hollow/Circular/Oval/(Solid Type, Spill through type etc.)
10	Abutment Material	CC/RCC/Masonry
11	Type of carriageway	Single/Intermediate/ Double/ Multilane/Divided etc.
12	Wearing coarse	Concrete/Bituminous
13	Shoulder Type	
14	Shoulder width in m	
15	Foot Path (LHS/RHS/Both)	
16	Footpath Type	
17	Kerb Type	
18	Kerb width in m	
19	Guard Rail/Parapet Type	Steel / Concrete / Aluminium / Closed / Open etc.
20	Drainage system	
21	Waterproofing	
22	Type of bank protection used along the waterway in the vicinity of the culvert	No Bank Protection / Rip-Rap, Dry / Rip-Rap, Grouted / Block / Granular Fill / Cribbing, Concrete / Cribbing, Steel / Steel Sheeting / Gabions / Stone Filling / Concrete, any other
23	End Treatment Type (Culvert Extensions)	Steel / Weathering Steel (Use even if the weathering steel is painted.) / Special Steel / Hybrid Steel Section (e.g., One type of steel for

		web, another type for the flanges.) / Corrugated Steel / Wrought or Cast Iron / Aluminum / Masonry / Concrete, Unreinforced / Concrete, Reinforced / Prestressed Concrete, Post- Tensioned / Prestressed Concrete, Pre-Tensioned / Polyethylene, Smooth Interior / Polyethylene, Corrugated Interior / Polyvinyl Chloride / None (Culvert has not been extended) / any other
24	Specific comments, if any	
Geometric Data		
1	Total (out to out) length of culvert in 'm'	
2	Total number of spans	
3	Length of Maximum Span in m	
4	Maximum Span material	Steel, Weathering Steel or any special steel, Hybrid Steel Section (e.g., One type of steel for web, another type for the flanges.), Corrugated Steel, Wrought or Cast Iron, Aluminum, Timber, Masonry Unreinforced Concrete, Reinforced Concrete, Prestressed Post-Tensioned Concrete, Prestressed Pre-Tensioned Concrete, Polyethylene- Smooth Interior, Polyethylene-Corrugated Interior, Polyvinyl Chloride Any other (Not listed above.)
5	Width of carriageway in m	(between inner to inner edge of kerbs/crash barrier)
6	Width of footpath in m	(Please also mention whether the footpath is raised and whether it is provided on both sides or only on one side)

7	Overall width of deck in m	(from outer to outer)
8	Overall length	
9	Overall width	
10	Number of lanes	
11	Number of beams	(to be picked up for each type of spans)
12	Depth of cover	
13	Span of masonry arch	
14	The rise of arch at the crown	
15	The rise of arch barrel at the quarter points	
16	The thickness of the arch barrel adjacent to the keystone	
17	The average depth of fill between road surface and arch barrel	
18	Height of parapet	
19	Height of columns piers	
20	Thickness of wearing course	
21	High Level or Submersible	
22	Most predominant stream bed material in the area of the culvert.	Bed Rock / Large Stone / Gravel / Sand / Silt / Clay / No Waterway / Other

23	Whether located in back waters/chemical zone	Lakes/Reservoirs/Streams/Rivers/Canals
24	Whether Marshy/Protected	
25	Drainage Pattern	
26	Length under Submergence in m	
27	Length under Water logging in m	
28	Design High Flood Level (HFL)	
29	Abnormal Flood Level	
30	Low Water Level	
31	Ground Level	
32	Height of slab/superstructure in mm	
33	Average Rainfall in mm for each month	
34	Design Velocity m/s	
35	Design Discharge in Cumecs	
36	High Tide Level	
37	Low Tide Level	
38	Design Scour Level at Pier	
39	Design Scour Level at Abutment	
40	Is any special access required to inspect the culvert	

41	Specific comments, if any	
Traffic Data		
1	Traffic Volume (Through/Cross in)	PCU/CVD
2	Suspension of Traffic if any	
3	Duration of Suspension of Traffic	
4	Documentation of traffic data	
5	Brief description of accident if any classification e.g. Fatal, Grievous Injury, etc.	
6	Brief description of accident nature e.g. Overturning, Head on collision, etc.	
7	Probable reasons for accidents (Engineering, Driver etc.)	
8	Vertical Clearance in m	
9	Horizontal Clearance in m	
10	Specific comments, if any	
Loading Data		
1	Pay load to be carried over the bridge. (GVW)	
2	Whether the culvert is load-posted, load-restricted or closed.	
3	Date on which the posting, restriction or closure was applied to the	
4	Specific comments, if any	

Land data		
1	Type of Terrain	Hilly/Mountainous/Plain/Meandering
2	ROW in m	
3		Whether agriculture/Industrial/Urban/Restricted/Forest/ Wild life/Sanctuaries/Any other
4	Year of holding/transfer (Date of Mutation)	
5	Whether Forest/Wild Life Sanctuaries/National Parks/ Industrial parks/Markets/ Missing Links/ Any other	
6	Whether Marshy/Protected	
7	Area in Ha.	
8	Type of Soil	(Soft/Granular/Sandy/BC/Moorum/Clay/Silty/ Sandy/Any other)
9	Founding Strata	Alluvial, Moorum, Rock
10	Bearing capacity of soil	
11	Specific comment, if any	
Environmental Data		
1	Temperature (Daily/Monthly/Average)	
2	Humidity	Air/Water/Temperature/Humidity/Noise
3	Air Quality	
4	Snow fall duration/Thickness	
5	Earthquake/Seismic Zone	
6	Climatic Zone	
7	Whether subjected to contaminate water?	

8	Whether subjected to harmful chemicals & gases?	
9	Whether culvert waters discharge into a river?	
10	Specific comment, if any	
Contact Details		
1	**(HQ/RO/Agencies/Police/ Any other**	
Any other Information / Comments		

APPENDIX-III

BRIDGE REGISTER

Implementing Agency:

Department:

Division:

Index

Sl. No.	Bridge/Culvert Structural Number	Page No.
1		
2		
3		

Original Bridge Report before issuing Completion Certificate It shall contain the following:

1. DPR or Feasibility Report
2. Detailed Design and Drawings as per actual
3. Proof Checking Reports
4. Dimensions, Material and Sectional Strength Properties
5. Deviation Report w.r.t. Design and Drawings
6. Soil/Borehole Data
7. All Quality Control Tests of various materials and finished product by Contractor
8. Inspection and Quality Control Reports by AE/IE/RO/PD etc.
9. Detailed Inspection Report (NSV/NDT) before opening to the traffic as per extant codes/guidelines
10. Contract Agreement
11. Comparative Statements of Estimated and Actual Costs
12. A Statement of Variations
13. Value Engineering done, if any

14. Environmental & Social Impact Assessment Report
15. Defect Liability Period
16. Contractor Details
17. AE/IE/RO/PD Details
18. Any specific mention about the project like new/innovative materials and techniques, performance monitoring mechanism etc.
19. Copy to the Ministry/RO and Implementing agency
20. Any other information.

APPENDIX-IV

INSPECTION PROFORMAE

Bridge Structural/ID Number:

1. Approaches Inspection Proforma

Id	Approaches sub-components	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no	Probable reasons	Maintenance actions required	Urgency
C1.1	Alignment								
C1.2	Signage								
C1.3	Embankment/ cutting								
C1.4	Railing/crash barriers / guard stones/ parapet								
C1.5	Approach slab								
C1.6	Approach joint								
C1.7	Side drains								
C1.8	Slope protection								

2. Substructure Inspection Proforma

Id	Substructure sub- components	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no.	Probable reasons	Maintenance actions required	Urgency
C2.1	Abutment								
C2.2	Abutment Cap								
C2.3	Dirt wall								
C2.4	Weep holes								
C2.5	Wing walls								
C2.6	Abutment protection works								
C2.7	Pier								
C2.8	Pier cap								
C2.9	Pier protection works								

3. Waterway/Channel Inspection Proforma

Id	Substructure sub-components	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no.	Probable reasons	Maintenance actions required	Urgency
C3.1	River/channel bed								
C3.2	Guide bunds								
C3.3	Spurs								
C3.4	Retaining wall								
C3.5	Toe walls								
C3.6	Floor/channel protection								
C3.7	Apron								
C3.8	Curtain/cut off walls								
C3.9	Ground/rock anchors								

4. Foundations Inspection Proforma

Id	Foundations sub-components	Distress type	Location	Extent of Distress	Severity of Distress	Condition State no.	Probable Reasons	Maintenance actions required	Urgency
C4.1	Foundations (raft/open/ pile/well)								
C4.2	Apron								
C4.3	Foundation protection								

5. Superstructure Inspection Proforma

Id	Superstructure sub- components	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no.	Probable reasons	Maintenance actions required	Urgency
C5.1	Girders /Main beams/Cables								
C5.2	Cross beams/diaphragms/ Suspenders								
C5.3	Articulation								
C5.4	Deck slab								
C5.5	Cantilever slab								
C5.6	Joints								

6. Appurtenances/Auxiliary Works Inspection Proforma

Id	Appurtenances/ Auxiliary works sub-components	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no.	Probable reasons	Maintenance actions required	Urgency
C6.1	Wearing surface								
C 6.2	Footpaths								
C6.3	Expansion joints								
C6.4	Pre-stressing elements (anchorages etc.)								
C6.5	Median								
C6.6	Kerbs/cornices								
C6.7	Light posts								
C6.8	Drainage spouts								
C6.9	Parapet/railing/ guard stones/crash barrier								
C6.10	Waterproofing system								
C6.11	Painting system								
C6.12	Utilities								

7. Bearings Inspection Proforma

Id	Bearings sub-components	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no.	Probable reasons	Maintenance actions required	Urgency
C7.1	Bearings								
C7.2	Bearing seats/caps								
C7.3	Earthquake restraints								
C7.4	Top Plate								
C7.5	Bottom Plate								

8. Culvert Inspection Proforma

Sl. No.	Culvert Component	Distress type	Location	Extent of Distress	Severity of Distress	Condition state no.	Probable reasons	Maintenance actions required	Urgency
1	Bed								
2	Apron								
3	Cut off Wall								
4	Type of Culvert- Pipe, Slab, Box etc.								
5	Parapet Wall/Railing/Crash barriers								
6	Signs & marking								
7	Wearing course								
8	Slope Protection								
9	Shoulder								
10	Any other								

APPENDIX-V

INSPECTION REPORT

1. Name of the Bridge/ID of the bridge:
2. Type of Inspection:
3. Date of Inspection:
4. Duration of Inspection: From am/pm to am/pm
5. Inspection Proformae: Shall include the following but not limited to: Structural deficiency, Location, Nature and extent of deficiency, Probable causes, Seriousness of deficiency, anticipated problems, Preventive measures, Expected cost of repairs with its urgency, Reference to the previous inspection reports and follow up action.
6. Photos/videos/sketches preferably geo-tagged
7. Specific comments, if any wrt.
8. Every inspection report shall be appended with the following certificate:

CERTIFICATE

(To be accorded by the inspector/official)

Certified that I have personally inspected this bridge and all entries have been verified at the site

Date: **Signature of**

the Inspector/Officer in-charge

All the reports are to be cross-verified by officers of the implementing agencies.

APPENDIX-VI

LIST OF EQUIPMENTS

i) Water proof clipboard

ii) Marking pencil, pen, paint and brush

iii) Torch

iv) Straight edge

v) Small tape with level tube and 30 m tape

vi) String and plumb-bob

vii) Pocket Knife

viii) Chipping hammer

ix) Wire brush, scrapper

x) Trowel

xi) Set of spanners

xii) Crack gauges, callipers, filler gauges

xiii) Square Spike

xiv) Hand Drill

xv) Saw

xvi) First Aid Box

xvii) Warning signs (men-at-work), safety cones and red flags

xviii) Reflective Helmet and reflective yellow rain-coat/ High visibility safety jackets/goggles

xix) Long rope

xx) Long rod

xxi) Ladder and Boat

xxii) Hydraulic jacks, pulley blocks, wire ropes, chains, slings etc. of appropriate capacity,

xxiii) Plastic Bag & Jars

xxiv) Binoculars

xxv) Camera

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/ Manual etc. from the date specified therein)

Price: ₹1000/-
(Plus Packing & Postage)